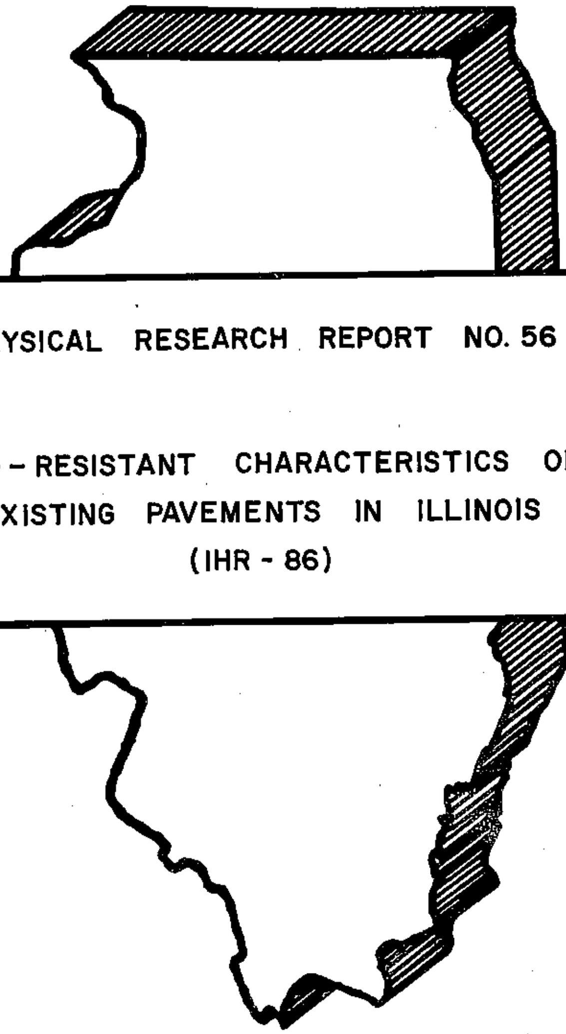
STATE OF ILLINOIS

DEPARTMENT OF TRANSPORTATION



PHYSICAL RESEARCH REPORT NO. 56

SKID-RESISTANT CHARACTERISTICS OF EXISTING PAVEMENTS IN ILLINOIS (IHR-86)

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16. Abstract

Over 8,300 skid tests were made between 1969 and 1971 at 404 sites on existing Interstate, primary, and county highways in Illinois. They indicate that textured portland cement concrete surfaces on two-lane highways can provide skid numbers (SN) above 35 throughout most of their 20-year design life as long as studded tire wear is negligible, but most multi-lane highways will need rejuvenating by grooving or by adding a friction course some time during their service life. Bituminous concrete surfaces generally have a lower value and a wider range of SN than PCC pavements. In northern and central Illinois, most two-lane bituminous concrete surfaces, which usually contain dolomite or crushed gravel, can provide an SN above 35 throughout most of their 15-year design life, while similar surfaces containing soft limestone in southern Illinois will need a hard skid-resistant aggregate blended with limestone to maintain an SN above 35. Also, multi-lane highways resurfaced with bituminous concrete will need a hard skid-resistant aggregate blended with or substituted for limestone to keep an SN above 35. Specific recommendations are included for improving skid resistance and for obtaining additional information needed for further improvement.

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DEPARTMENT OF TRANSPORTATION
Division of Highways
Bureau of Materials and Physical Research

SKID-RESISTANT CHARACTERISTICS OF EXISTING PAVEMENTS IN ILLINOIS

By

Philip G. Dierstein and Donald R. Schwartz

Interim Report
IHR-86
Skid Resistance of Pavement Surfaces

A Research Project Conducted by
Illinois Department of Transportation
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

October 1975

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IN ILLINOIS

INTRODUCTION

Of the principal factors involved in skidding accidents, the pavement is the one that mostly interests highway engineers. Past research and experience have confirmed that a pavement can indeed be slippery when wet. In fact, wet pavements usually have about one half the skid resistance of dry pavements (1), and according to the annual Summary of Motor Vehicle Traffic Accidents, wet pavements are associated with approximately 20 percent of the motor vehicle accidents in Illinois. Although this percentage seems small, its importance is realized when related to the amount of time the pavement is wet. Illinois State Water Survey Records indicate that measurable precipitation lasts, on the average, from 5 to 6 percent of the number of hours in a year (2). Obviously, when 20 percent of the vehicular accidents occur in 5 to 6 percent of the available time, wet-pavement accident rates must indeed be higher than dry-pavement accident rates. This fact concerns not only Illinois highway engineers but also highway engineers nationwide.

The Illinois Department of Transportation, recognizing this fact, undertook a five-phase research study entitled IHR-86, "Skid Resistance of Pavement Surfaces," in 1967, in cooperation with the Federal Highway Administration. This report presents the findings of Phases 2 and 3 whose objectives are to determine the skid resistance of highways and intersections, and to study the polishing characteristics of aggregates in these pavement surfaces. To achieve these objectives, more than 8,300 skid tests were made with a two-wheel skid-test trailer, developed in Phase 1, at over 400 sites throughout Illinois between 1969 and 1971.

The findings indicate that most two-lane portland cement concrete pavements in central and southern Illinois and most two-lane Class I bituminous concrete surfaces in northern and central Illinois where gravel and dolomite sources prevail can provide adequate skid resistance throughout much of their structural service life. Special surfaces for skid resistance, however, may be needed initially and possibly again later during the life of many multi-lane highways, particularly those in metropolitan areas. The skid resistance of portland cement concrete pavements in northern Illinois, where 13 percent of the vehicles are equipped with studded tires, dropped to a mean SN of 35 after only 7.3 million axle applications as compared with 78 million applications for the rest of the State. Conversely, the skid resistance of Class I bituminous concrete surfaces in southern Illinois that contain soft limestone dropped to a mean SN of 35 after only 2.1 million axle applications as compared with 95 million axle applications in the rest of the State. Moreover, vehicular traffic lowers skid resistance faster at intersections, particularly at those having a bituminous surface, than along the open highway.

The sections that follow discuss details of the study, describe the skid resistance of PCC and of bituminous concrete pavements found on the interstate and primary systems, characterize the skid resistance of bituminous concrete and bituminous surface treatments usually found on the County system, and close with a discussion, conclusions and recommendations.

STUDY DETAILS

Skid testing for Phases 2 and 3 began in July 1969, continued through the summer and fall of 1970 and ended in the summer of 1971. The field work lasted longer than originally expected because of continual minor equipment breakdowns and because of extra time needed for traffic protection at intersections and in urban areas. Also, the amount of time necessary to interpret chart recordings and to compute skid numbers from them was much greater than originally anticipated.

This section describes how 404 sites were selected for study, tells what procedure was used in making over 8,300 skid tests at the selected sites, and explains what methods were used in analyzing the test results.

Site Selection

To obtain a sample that represents the skid resistance of Illinois highways, the District Engineer in each of the nine highway districts was asked to select as many sites as possible from a site selection chart which is shown in Figure 1. In this way, the District Engineers were expected to submit a representative cross section of existing pavement surfaces under their jurisdiction and, in turn, the selected test sites, when tabulated for the entire state, were expected to provide an adequate sample for study.

The chart in Figure 1 incorporates five factors, all of which are believed to influence skid resistance to some degree. They are pavement type, pavement age, general location, aggregate type, and traffic volume. As can be seen in the figure, the five factors are divided further into sub-factors.

Pavement surfaces of the interstate and the primary system in Illinois usually are portland cement concrete and bituminous concrete, while those paved surfaces of the County system are mostly bituminous surface treatments and bituminous concrete. Bituminous concrete surfaces are divided further into Class I mixtures, which are placed mainly on existing rigid surfaces of the primary system, and Class B mixture, which usually are placed on flexible bases of the County system. In addition to the above categories, nearly all surface types were separated as to whether or not they contained either gravel or crushed stone coarse aggregate.

As for general location, the sites were straight, level, 1-mile sections of open highway and 500-ft approaches to stop intersections.

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Bureau of Research and Development

CHART FOR SELECTION OF SKID TEST SITES

DISTRICT

TYPE OF PAVEMENT SURFACE	PORTLAND CEMENT CONCRETE (1)											
GENERAL LOCATION	OPEN HIGHWAY (1)						STOP INTERSECTION (2)					
KIND OF COARSE AGGREGATE	GRAVEL (1)			CRUSHED STONE (2)			GRAVEL (1)			CRUSHED STONE (2)		
TRAFFIC VOLUME	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3
AGE OF SURFACE (years) 0	●	x	x	x	x	x	●	●	x	x	●	●
1	x	x	x	x	x	x	x	●	●	x	●	x
2	x	x	x	x	x	x	●	●	x	●	x	●
3	●	x	x	x	x	x	●	●	x	●	x	●
5-6	x	x	x	x	x	x	●	x	x	x	x	x
10-12	x	x	x	x	x	x	x	x	●	x	x	x

TYPE OF PAVEMENT SURFACE	BITUMINOUS CONCRETE													
	I-11 (2)						B-5 (3)							
GENERAL LOCATION	OPEN HIGHWAY (1)			STOP INTER-SECTION (2)			OPEN HIGHWAY (1)				STOP INTERSECTION (2)			
KIND OF COARSE AGGREGATE	CRUSHED STONE (1)			CRUSHED STONE (2)			GRAVEL (1)		CRUSHED STONE (2)		GRAVEL (1)		CRUSHED STONE (2)	
TRAFFIC VOLUME	V_1	V_2	V_3	V_1	V_2	V_3	V_4	V_5	V_4	V_5	V_4	V_5	V_4	V_5
AGE OF SURFACE (years) 0	x	x	x	x	x	x	●	x	x	x	●	x	●	●
1	x	x	x	x	x	●	x	●	x	x	●	●	●	x
2	x	x	x	x	x	x	x	x	x	x	x	●	x	●
3	x	x	x	x	x	x	x	x	x	x	x	x	x	x
5-6	x	x	x	x	x	x	x	x	x	x	x	●	x	x
10-12	x	x	x	x	x	x	x	●	●	x	●	●	●	●

TYPE OF PAVEMENT SURFACE	BITUMINOUS SURFACE TREATMENT (Class A) (4)							
GENERAL LOCATION	OPEN HIGHWAY (1)				STOP INTERSECTION (2)			
KIND OF COARSE AGGREGATE	GRAVEL (1)		CRUSHED STONE (2)		GRAVEL (1)		CRUSHED STONE (2)	
TRAFFIC VOLUME	V_4	V_5	V_4	V_5	V_4	V_5	V_4	V_5
AGE OF SURFACE (years) 0	x	x	x	x	x	x	x	x
1	x	x	x	x	x	x	x	x
2	x	x	x	x	x	●	x	x
3	x	x	x	●	x	x	x	x

Note: The numbers enclosed by parentheses indicate appropriate code numbers. See coding instructions.

TRAFFIC VOLUME LEVELS (1967 ADT)

V_1	Under	2500
V_2	2500 -	4999
V_3	5000 and	Over
V_4	Under	400
V_5	400 and	Over

R/D 8-1-68

x Test sites selected.
● No test site selected.

Figure 1.

The age of portland cement concrete and bituminous concrete surfaces varied from new (age 0) to 12 years, while that of bituminous surface treatments ranged from new to 3 years. For this study, age zero represents any surface that has been open to traffic for less than 3 months; age 1 represents a surface that has been open to traffic from 3 months to 18 months; age 2 represents any surface that has been open to traffic from 1 1/2 years to 2 1/2 years, etc.

Referring again to Figure 1, traffic volumes used in selected test sites were based on 1967 average daily traffic (ADT), and were divided into five volume ranges. For the interstate and the primary system, traffic volume had three ranges - under 2,500 vpd, 2,500 to 4,999 vpd, and 5,000 and over vpd. The two ranges for the County system were under 400 vpd, and 400 vpd and over. Selecting sites within these volume ranges for each age group was expected to provide surfaces having an ample range of axle applications to evaluate a change in skid resistance.

In addition to selecting test sites, each District was asked to describe each site by furnishing the following:

(1) Site identification

(2) Pavement profile grade

(3) Source of fine and coarse aggregate

(4) Date pavement was opened to traffic

(5) Traffic volume and composition for each year since the pavement was open to traffic

Item 1 was needed to help the skid-test crew identify the site in the field, while items 2 through 5 were used later in the analysis of field data.

Test sites selected by the Districts totalled 404 out of a possible 1,880, which are summarized in Table 1 by highway system, by pavement type, and by general

TABLE 1

SUMMARY OF TEST SITES

Highway System	Pavement Type	Number of Sites: Open Highway	Number of Sites: Stop Intersection	Number of Sites: Total	Percent of Total
Interstate and Primary	PCC Concrete	85	30	115	29
	Bituminous Concrete Class I	118	56	174	43
	Subtotal	203	86	289	72
County	Bituminous Concrete Class B	26	14	40	10
	Bituminous Surface Treatment-Class A	45	30	75	18
	Subtotal	71	44	115	28
	TOTAL	274	130	404	100

location. Statewide, sites were obtained for almost every category in the selection chart (Fig. 1), except under PCC and Class B bituminous concrete intersections where sites for about one half of the categories were not selected. Although every age level is represented under PCC intersections, sites are missing in one or two of the traffic volume levels. Under Class B bituminous concrete intersections, sites are missing not only in traffic volume levels but also at some age levels. Every District supplied PCC and Class I bituminous concrete sites, but several Districts completely omitted sites under Class B bituminous concrete and Class A bituminous surface treatments. Although the stratified sample (21 percent) is smaller than expected and contains some random omissions, the selected sites still are believed representative of highway surfaces in Illinois. As can be seen in Table 1, the interstate and the primary system account for 72 percent of the sites, as compared to 28 percent on the County system. Open-highway sections represent two thirds of the sites, with the remaining one third representing stop intersections. Moreover, the number of sites for each pavement type is nearly proportional to mileage on the Interstate and primary systems, and is somewhat less proportional to that on the County system.

Test Equipment

As previously mentioned, the equipment used to make skid tests in Phases 2 and 3 was developed and calibrated during Phase 1 of the study. Consisting of a tow vehicle and a two-wheel trailer, the system was designed in accordance with criteria established in ASTM Designation: E 274-65T, Skid Resistance of Pavement Using a Two-Wheel Trailer. Further details about the system selected were reported by Kubiak in March 1970 (3).

The equipment, fabricated by Soiltest Inc., Evanston, Illinois, was delivered to the Division of Highways in May 1968. After several modifications were made during equipment shakedown tests, the system was calibrated and became operational in July 1969.

In April 1972, Kubiak, et al, reported on the "Modifications and Calibration of the Illinois Skid Tests System" (4). Only a brief description of the system is repeated here for convenience. The skid trailer features leaf spring suspension, electric brakes, and a brush-type water applicator. The tow vehicle, which is a 2-axle, 6-tire truck, carries a 450-gallon water tank. Inside the truck cab are mounted power supplies, amplifiers, and recording instruments. Skid resistance is measured as a function of torque produced in the trailer axle when the wheels are locked. The torque, obtained when the brake is locked, is recorded by an analog chart recorder. Later, in 1972, a digital printer was added to reduce the time required to obtain an SN from chart recordings.

Test Procedures

Skid tests are made at 40 mph in accordance with ASTM Designation: E 274-65-T. As the driver attains test speed, he engages the automatic speed control; then, the operator presses the test button each time a test is desired. Pressing the test button activates the test program, which includes starting and stopping the self-watering system and locking the brakes for three seconds. Each test represents a single-wheel lockup, either in the left wheelpath of traffic lanes or in the right wheelpath of passing lanes. Inner wheelpaths were chosen for testing because experience indicates they usually are the most polished surface.

As previously mentioned, the test sites comprised straight, level, one-mile open-highway sections and 500-ft approaches to stop intersections. The skid number obtained at open-highway sites is the average of 10 tests in each lane, while the skid number obtained at intersections represents the average of six tests per lane. When testing four-lane highways, both traffic and passing lanes were tested and reported separately because of a difference in wear between lanes.

Data Analysis

To achieve the objectives of Phases 2 and 3, the skid numbers obtained by the skid crew were analyzed in two different ways. First, the average skid number for each type of surface was related to the number of cumulative axle applications that had passed over that surface for each study factor. Then, the resulting skid number-cumulative axle curves, hereinafter called wear curves, were compared with one another to determine how the different factors affected skid resistance.

Axle applications for each site were determined by multiplying 2 axles for passenger cars, 2.1 axles for single-unit trucks and, depending on the year, from 3.8 to 4.8 axles for multi-unit trucks by their corresponding Annual Average Daily Traffic (AADT) which was supplied by the Districts. Axle applications were selected as the best way to relate mixed traffic to pavement wear. Although wheel load also apparently affects skid resistance (5), no known procedure for modifying the number of axle applications by an axle weight factor was available, and an initial attempt to relate mixed traffic to pavement wear through axle load equivalency factors was unsuccessful.

In addition to those comparisons, the wear curve for a particulate type of surface can be used to predict how long, on the average, that surface can be expected to provide a satisfactory skid number for a particular type of highway and for a given ADT and vehicle composition.

Even though the preceding method does characterize pavement skid resistance, it does very little to explain whether those surfaces have an adequate skid resistance. At this time, no Federal, AASHTO, ASTM or other standards for skid resistance exist. In fact, no general agreement exists as to what is a minimum skid number for specific situations. Kummer and Meyer, in NCHRP Report 37, have suggested tentative minimum requirements based on frictional demand. They recommend a minimum SN of 37 measured at 40 mph as a value that should satisfy the minimum frictional demand of a majority of motorists driving at a mean speed of 50 mph (1). Further, NCHRP "Research Results Digest No. 50" says that "A pavement can be considered deficient in skid resistance only in relation to the demand of traffic on it.....It is only when skidding occurs as a consequence of maneuvers that are within the range of normal demand (accelerations, braking, and cornering by a majority of drivers under normal traffic conditions) or intermediate demand (last-minute braking or steering corrections caused by inattention, misjudgment, or unusual incidents) that the pavement skid resistance should be considered inadequate." (6)

On the basis of the above information, in combination with our own experience, three separate levels of skid numbers were established to provide guidelines for estimating the general quality of skid resistance of Illinois pavements from the data collected in this study. The levels are: above 36, 30-36, and below 30.

Presentation of Results

Because PCC and Class I bituminous concrete surfaces usually serve as pavement surfaces for interstate and primary highways, which carry the bulk of traffic, and because Class B bituminous concrete and bituminous surface treatments serve as pavement surfaces for lightly traveled secondary and local highways, their results are presented separately in the following two sections.

RESULTS - INTERSTATE-PRIMARY SYSTEM

In Illinois, the interstate-primary system amounts to more than 13,000 miles, of which approximately 10 percent are marked as interstate highways, 29 percent are marked as U.S. highways, and 61 percent are marked as state highways. The interstate system, except for 100 mi of bituminous concrete, is portland cement concrete, while two thirds of the primary system is Class I bituminous concrete and one third is PCC surface.

Of the 203 open-highway sites examined, 118 were Class I bituminous concrete and 85 were portland cement concrete, and of the 86 stop intersections investigated, 56 were Class I bituminous concrete and 30 were portland cement concrete. Moreover, the distribution of PCC and Class I bituminous concrete test sites is nearly proportional to the mileage of PCC and Class I surfaces now in service.

This section first describes the skid-resistant characteristics of Class I bituminous concrete surfaces and then describes PCC surfaces. Next, bituminous concrete surfaces are compared to those of portland cement concrete. Finally, a method of predicting the mean expected skid life is presented.

Class I, Bituminous Concrete Surfaces

Class I bituminous concrete is a dense-graded aggregate (top size 2 1/2 in.) type bituminous mixture used primarily to resurface existing interstate and primary rigid pavements. To reduce consolidation under traffic and to provide a durable, long-lasting surface, this mix is designed for a low void (2 percent) content. The mixture is compacted to a density not less than 93 percent of maximum possible density of a voidless mixture composed of the same material in like proportions. As previously mentioned, this type of surface constitutes about two thirds of the mileage of the interstate-primary system.

Wear curves, which show the relation between SN and cumulative axle applications, in millions, for Class I open-highway sites and stop intersections, are shown in Figure 2. As can be seen in this figure, the mean SN of a Class I surface after 100,000 axle applications, which is considered a new pavement in

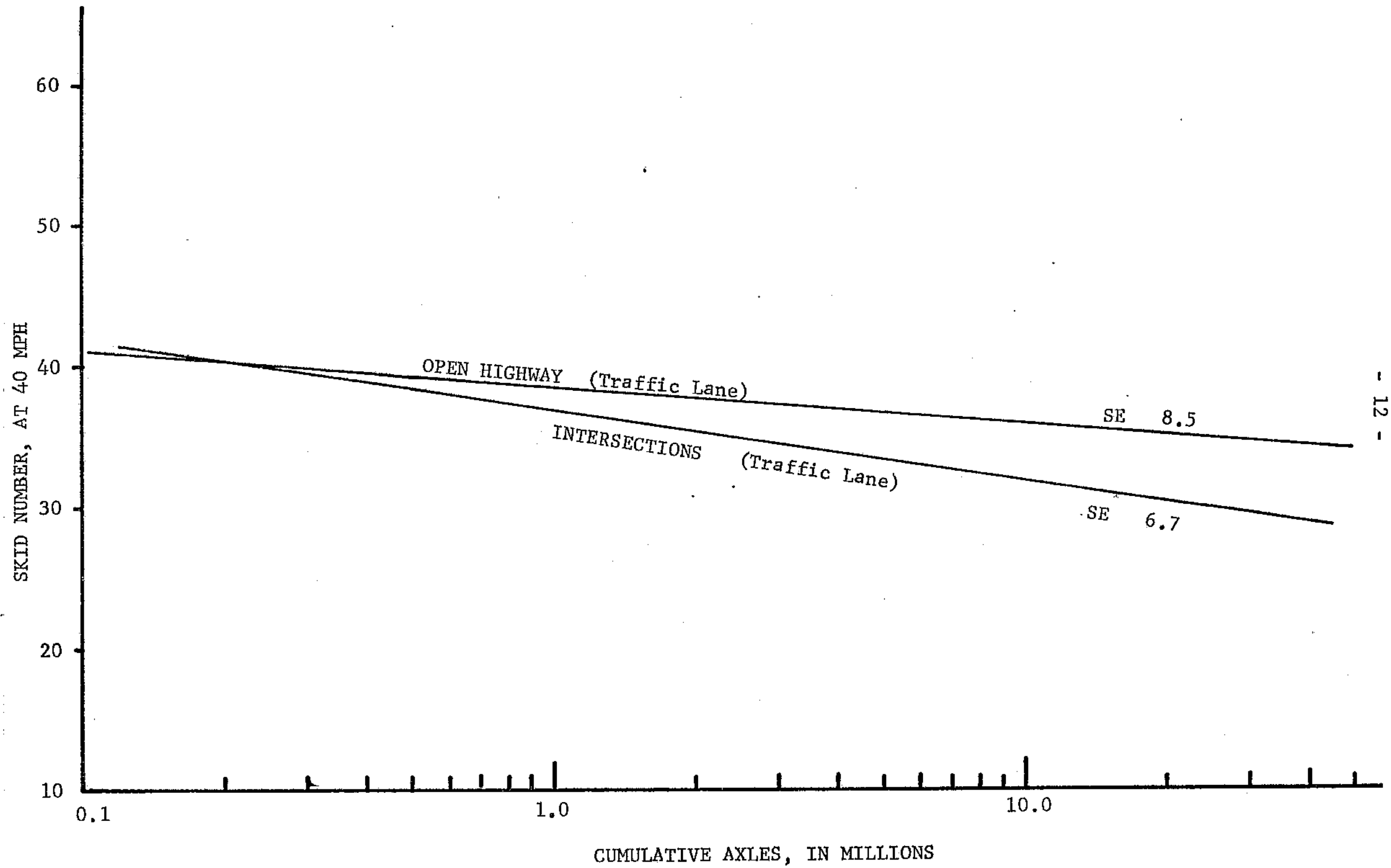


Figure 2. Wear curves for Class I bituminous concrete surfaces by location.

this study, is 41 but, as traffic wears the surface, the SN drops faster at intersections (SN 28 @ 50 M axles) than along the open highway (SN 34 @ 50 M axles). Moreover, visual inspections at a number of intersections indicate that, in addition to aggregate wear and polishing, their skid resistance is lower because heavy vehicles braking, standing, and accelerating at intersections consolidate and rut the surface, while any free asphalt migrates toward the surface, causing the surface texture to become smoother at the intersection than along the open highway.

Of the 118 open-highway sites tested, 25 sites were four-lane highways, which provided an opportunity of examining the difference in SN between traffic and passing lanes. When the passing lane is compared to the traffic lane, in Figure 3, the curve for the passing lane lies above that for traffic lanes but, as cumulative axle applications increased, the SN of both lanes not only dropped but also the difference widened. Passing lanes differ from traffic lanes primarily in the rate at which traffic is applied to them. The passing lane, for example, may take 18 years to accumulate 5 million axle applications as compared to one year in a traffic lane. So, for an equal number of axle applications, the surface of a passing lane is exposed much longer to weathering than a traffic lane. Weather oxidizes the asphalt in a bituminous mixture. In turn, the bond between the asphalt and the aggregate breaks, allowing aggregate to ravel away. This adds to surface roughness, which probably accounts for the difference in SN between passing and traffic lanes that have carried an equal number of axle applications. This will be discussed later in more detail.

To get a better picture of statewide pavement skid resistance, mean skid numbers for traffic lanes were sorted into the three previously mentioned skid-resistance levels and were compared by three geographical areas. For convenience,

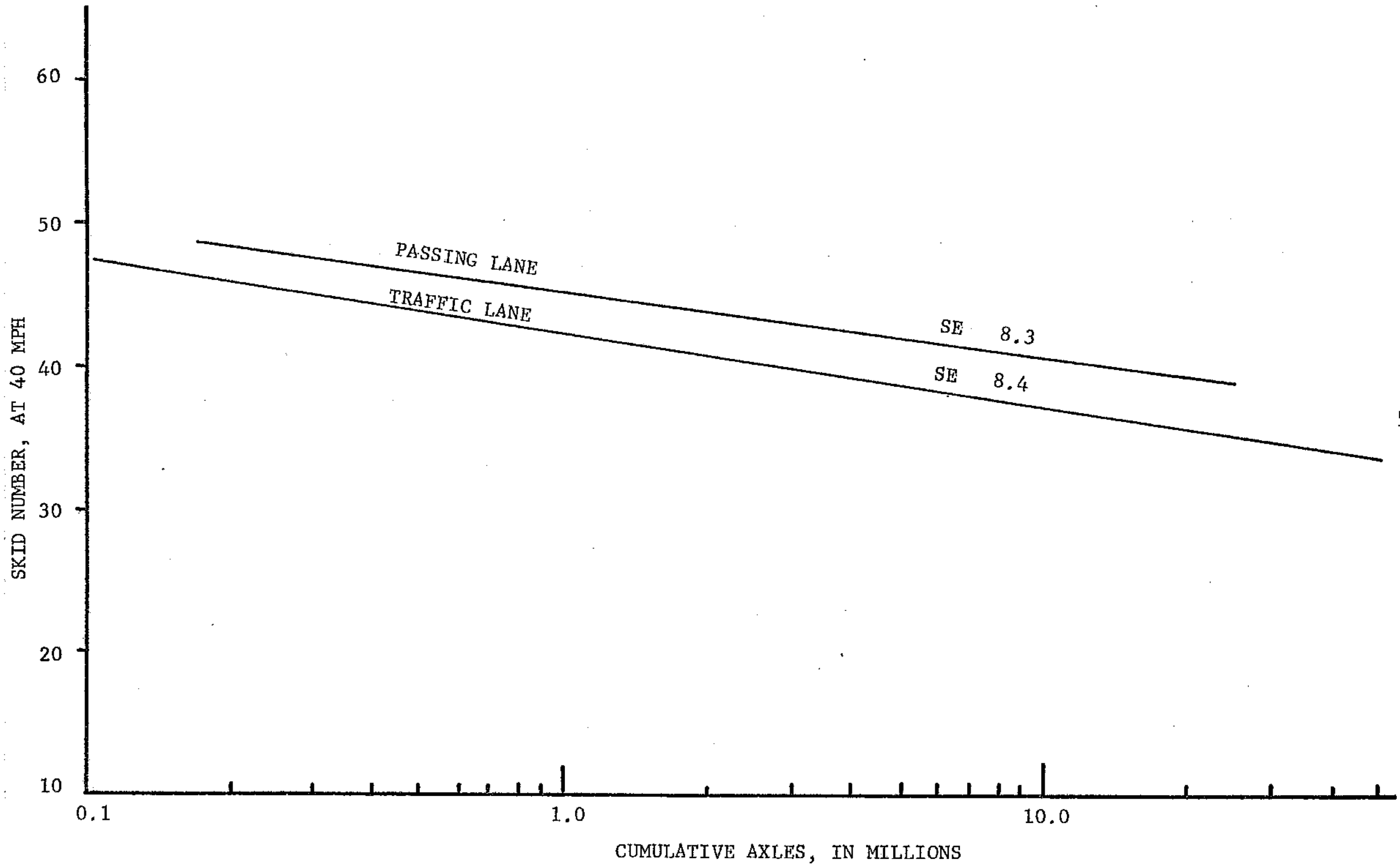
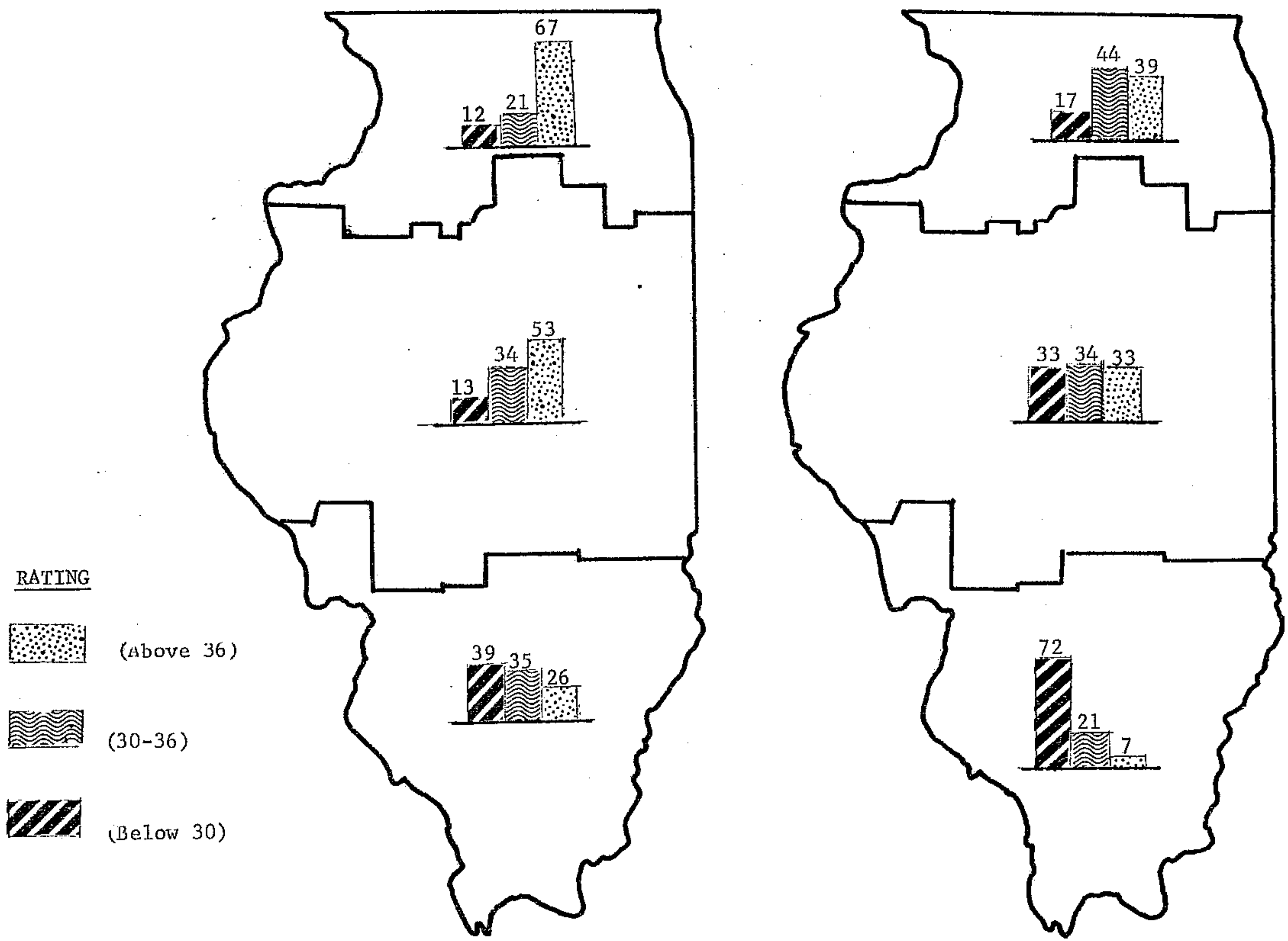


Figure 3. Wear curves for traffic and passing lanes of Class I bituminous concrete surfaces.

the boundaries of the geographical areas follow highway district boundaries. The northern area comprises Districts 1 and 2, the central area contains Districts 3, 4, 5, and 6, and the southern area comprises Districts 7, 8, and 9. The results of this grouping for open-highway sites can be seen in Figure 4a, and those for intersections are in Figure 4b. Assuming that the sample of test sites represents the geographical areas, we see that 39 miles out of 100 miles of Class I surface in southern Illinois probably would have an SN below 30 as compared to 13 miles out of 100 miles in the central area and 12 miles out of 100 miles in the northern part of the State. Now, looking at intersections (Figure 4b), the percent of sites having an SN below 30 is significantly greater for intersections, particularly in southern Illinois, than along the open highway. In southern Illinois, 72 out of 100 intersections can be expected to have an SN below 30 as compared to 33 out of 100 intersections in the central area and 17 out of 100 intersections in northern Illinois. Further investigation indicates that the reason for this wide geographical difference in SN seems to be related to the type of coarse aggregate used in Class I mixes.

A commonly accepted fact among those studying skid resistance is that the coarse aggregate used in bituminous concrete mixtures is the major factor affecting the skid resistance of that mixture. In Illinois, crushed stone is the major coarse aggregate used in bituminous concrete, but sometimes crushed gravel is used. Moreover, a number of crushed stone sources are classified as dolomite, which is harder than limestone. To see what effect these different coarse aggregates might have on skid resistance, relative frequency curves for limestone, dolomite, and gravel were prepared and are shown in Figure 5. As seen in the figure, 70 percent of the limestone sites had an SN of 30 or higher as compared



(a) Open Highway (Percent of test sites) (b) Intersections (Percent)

Figure 4. Skid resistance rating of Class I bituminous concrete surfaces by geographical areas.

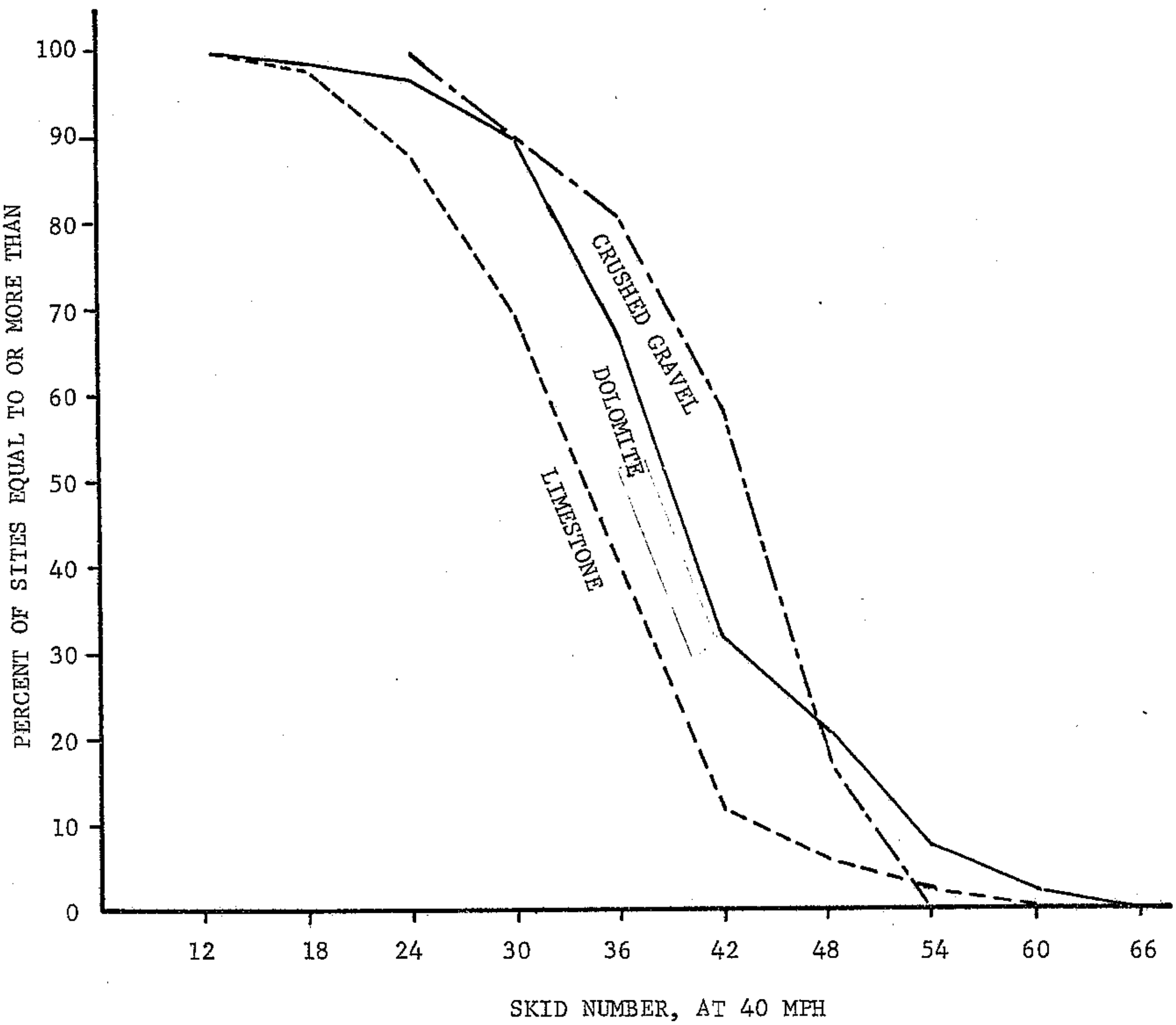


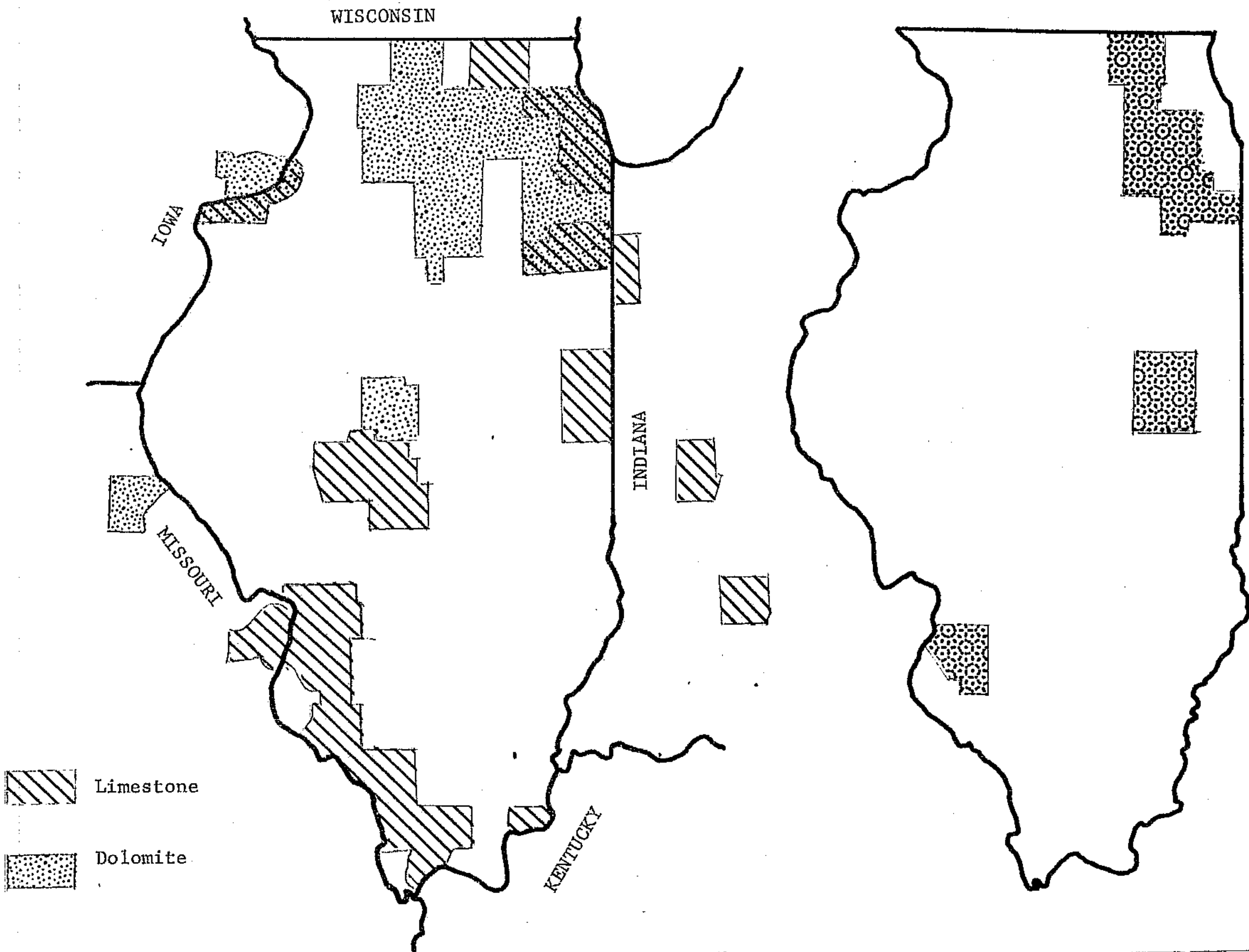
Figure 5. Cumulative frequency curves for skid resistance of Class I bituminous concrete surfaces by type of coarse aggregate.

with 70 percent for dolomite and 81 percent for crushed gravel. Obviously, the crushed gravel and the dolomite coarse aggregates provide higher skid numbers than the limestone coarse aggregates.

When the geographical source of each kind of aggregate is plotted on a map, the reason for a lower skid resistance occurring in southern Illinois becomes quite clear. Limestone and dolomite sources for the test sites are shown by county in Figure 6a, while gravel sources for the test sites are shown by county in Figure 6b. Referring first to Figure 6a, it can be seen that limestone, which has a Moh's hardness of 3, prevails mostly in the southern half of the State. On the other hand, dolomite, which has a Moh's hardness of 3.5 to 4, occurs mostly in the northern part of the State. The map also indicates that both limestone and dolomite quarries occur in three northern counties. Gravel aggregates, which have a Moh's hardness ranging from 3.5 to 6.5, depending on the source of the gravel, prevail mostly in the north as can be seen in Figure 6b.

Because the frequency curves indicated that skid resistance of Class I surfaces differs with the type of coarse aggregate used in the mixture, wear curves were prepared for traffic lanes by type of coarse aggregate and are compared in Figure 7 for open-highway sites and in Figure 8 for intersections. Of the 118 open-highway sites available for study, 56 sites having 110 test lanes contained limestone, 46 sites representing 88 test lanes contained dolomite, and the remaining 16 sites having 31 test lanes contained crushed gravel.

As expected, the wear curve for Class I mixtures containing limestone coarse aggregate (Figure 7) lies below (5-10 SN's) both the dolomite and the crushed gravel wear curves. As these surfaces are worn by traffic, the SN of dolomite surfaces, however, drops at a faster rate than that of crushed gravel surfaces,



(a) Crushed Stone Sources

(b) Crushed Gravel Sources

Figure 6. Map showing geographical source of coarse aggreate for Class I bituminous concrete surfaces.

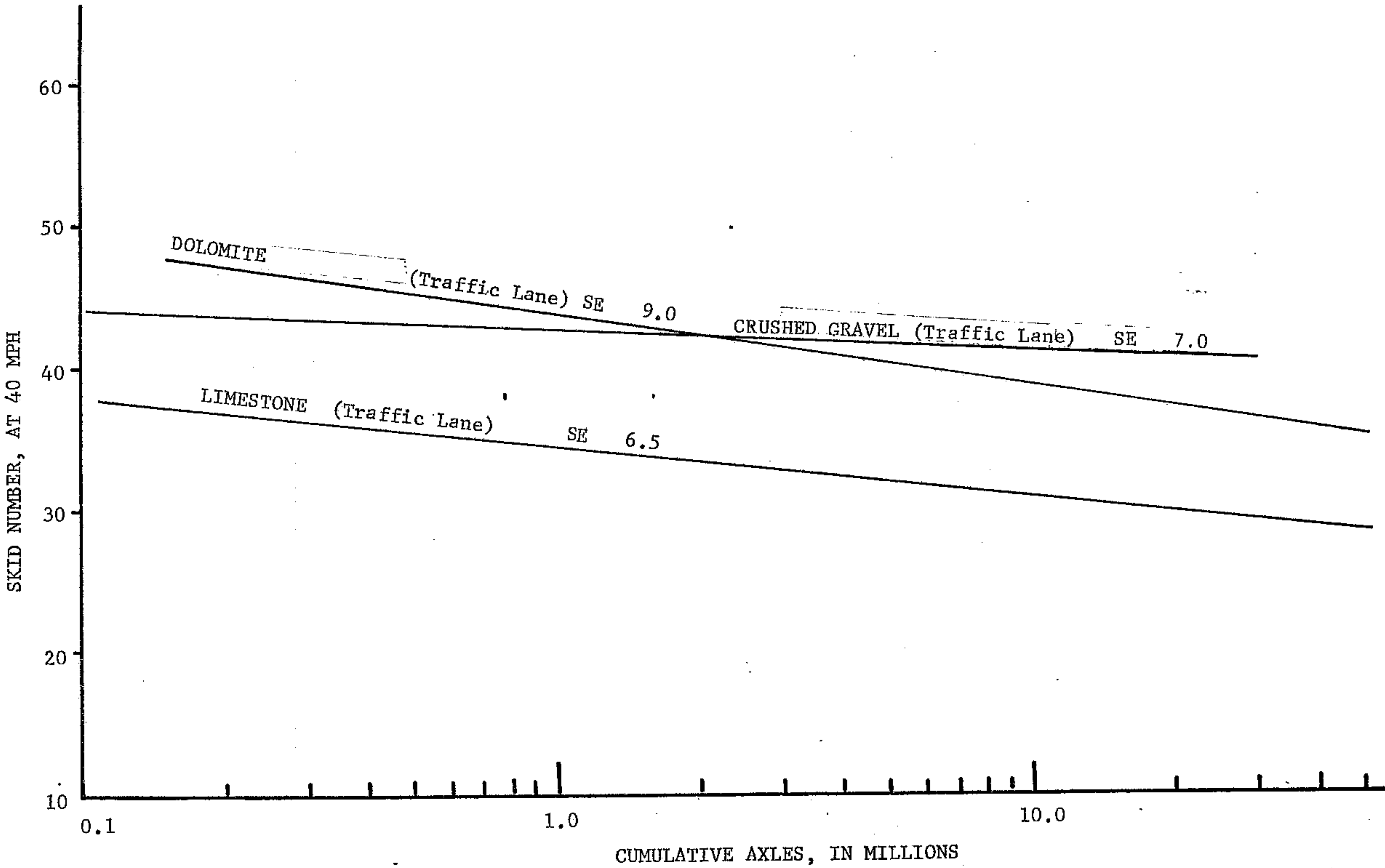


Figure 7. Wear curves for Class I bituminous concrete surfaces on open highway by type of coarse aggregate.

but even after 50 million axle applications the dolomite surface still has a mean skid number of 35, which is only 2 skid numbers lower than the tentative minimum skid number of 37 recommended by Kummer and Meyer (1). Although it seems logical for the crushed gravel curve to be higher than the dolomite curve, the gravel curve may contain some bias because it represents only one third as many sites as does the dolomite curve.

Another interesting point about these curves is that the standard error of estimate of the limestone curve (6.5) and of the crushed gravel curve (7.0) is smaller than that of the dolomite curve (9.0). The wider deviation of points about the dolomite curve probably reflects the varying amounts and grain sizes of silica sand found in different dolomite sources.

Of the 56 intersections available for study, 26 intersections (31 lanes) contained limestone, 25 intersections (33 lanes) contained dolomite, and 5 intersections (8 lanes) contained crushed gravel. Looking at the wear curves for intersections in Figure 8, we see that they are arranged similar to those for open highway - the gravel curve lies above while the limestone curve lies below the dolomite curve, but they all converge after 44 million axle applications at a mean skid number of 28.

The limestone curves for both intersections and open highway are almost identical, but the dolomite curve for intersections lies from 6 to 7 skid numbers below its corresponding open-highway curve. Had more pavements containing gravel been tested, the slope of the gravel curve probably would have been flatter, yet still several skid numbers above the dolomite curve after 100,000 axle applications. Then, too, it probably would have been below its corresponding open-highway curve.

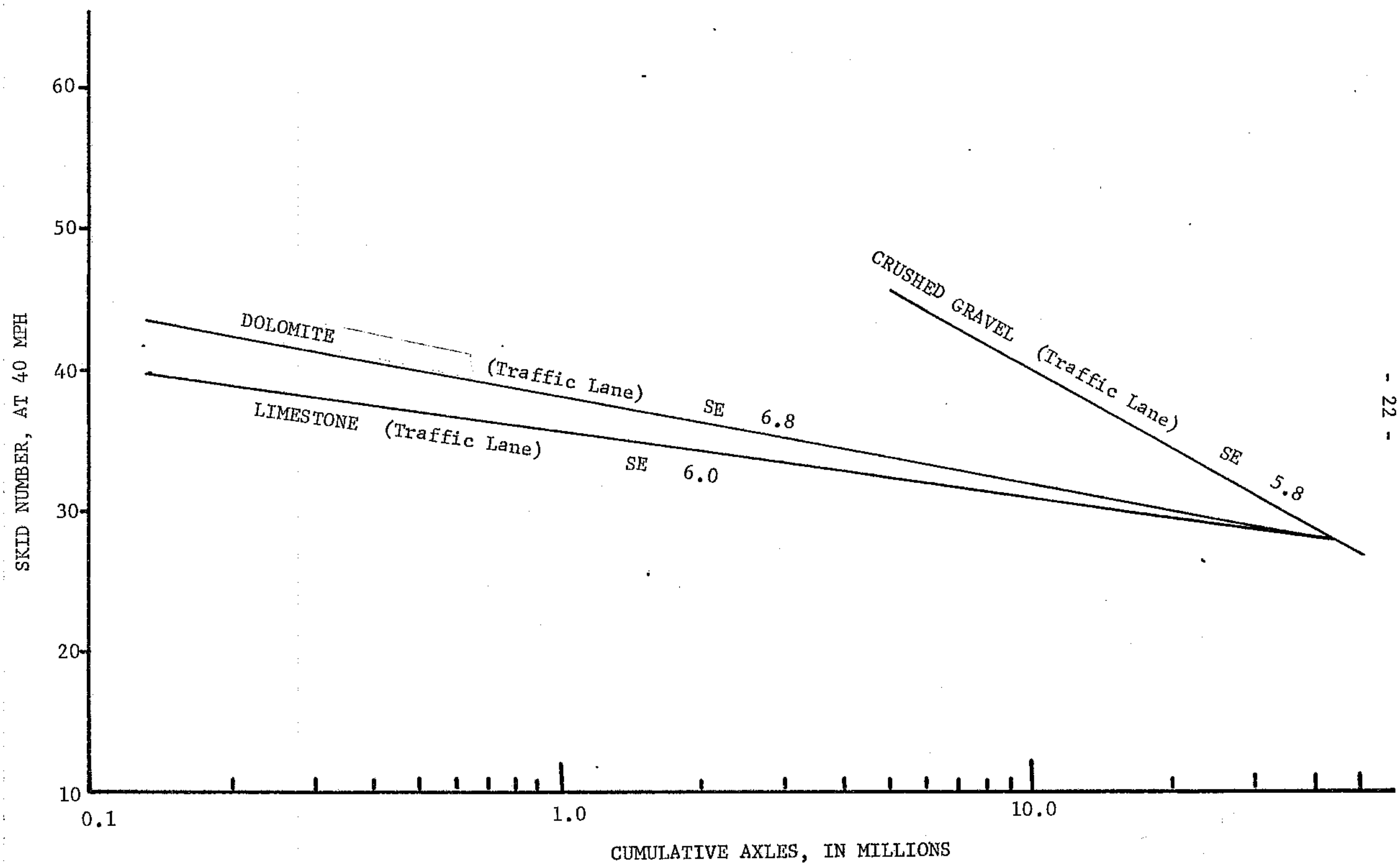


Figure 8. Wear curves for Class I bituminous concrete at intersections by type of coarse aggregate.

Pavement age, another factor in the study, interacts with traffic volume to affect skid resistance. Earlier, when wear curves for the traffic and passing lanes were compared, it was mentioned that age in the form of weathering may enhance skid resistance for an equal number of axle applications.

Highway engineers generally accept the fact that the asphalt in a bituminous concrete mixture oxidizes with age, but Zube and Skog (7) believe that the rate at which it oxidizes is related to the air voids in a mixture and that good compaction during construction lowers voids in a mixture and retards oxidation. This also tends to support the belief that asphalt in surfaces placed on heavily traveled streets and highways stays alive because traffic continuously kneads and compacts the surfacing, thereby reducing the void content.

To further explore this possibility, both open-highway sites and intersections were sorted into four groups according to total cumulative axle applications at time of testing - under 2 million, 2 to 6 million, 7 to 15 million and 16 million and over. Then, mean skid numbers were calculated and compared by pavement age at the time of testing for the sites in each of the four groups. Preliminary analysis indicated that the data for open-highway sites and for intersections were similar, so they were pooled together and are plotted in Figure 9. For unknown reasons, the curves seem to follow a cycling pattern, which is more distinct in the younger (up to 7 years) pavements than in the older pavements which represent fewer sites. In fact, about one third of the points for 8-year and older surfaces represent only one site, while those points for younger surfaces represent from 2 to 14 sites.

While no strong trends are indicated by the limited data, the flat slope of the under 2 million curve and the general upward slope depicted by the 2- to

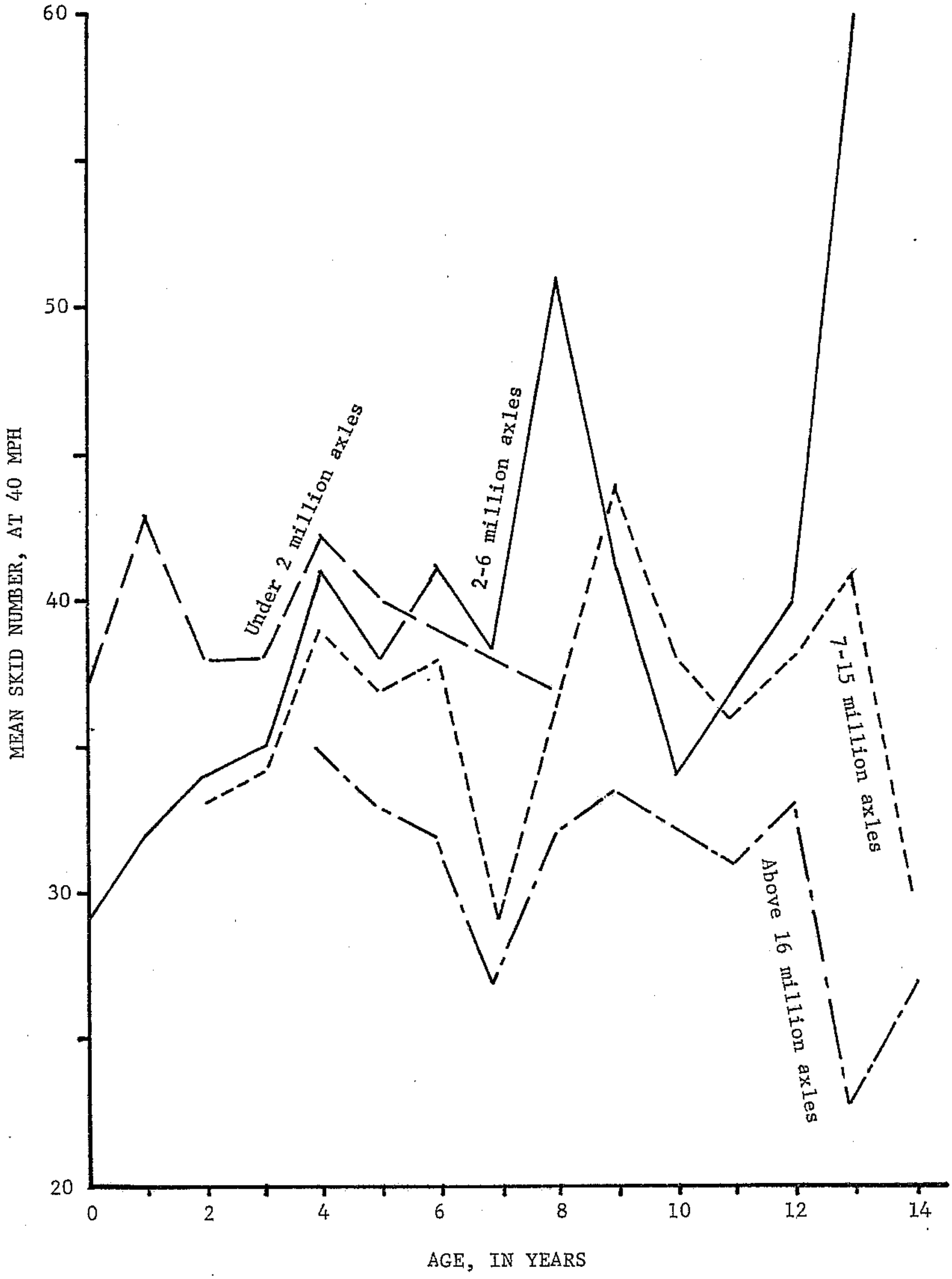


Figure 9. Change in skid number of Class I bituminous concrete surfaces with age.

6-million and the 7- to 15-million curves suggests that weathering may affect the rate of change in skid number of bituminous concrete surfaces, especially in lightly traveled routes. In the 2- to 6-million axle applications curve, for example, a two-lane pavement in service for two years has carried 2,400 vpd as compared to 600 vpd for a pavement in service eight years. Although the sites represented by this curve have carried about the same number of applications, they differ mainly in the rate of applications applied to their surfaces. All other things being equal, an older bituminous concrete surface can be expected to have a higher SN at a given number of axle applications than a younger surface having received the same number of applications. However, when the total axle applications are above 16 million, aggregate wear and polishing seem to overshadow the effect of weathering. This analysis suggests weathering influences skid resistance of bituminous surfaces, but further evidence is needed to confirm this observation.

Portland Cement Concrete Surfaces

New interstate and primary highway pavements in Illinois usually are constructed of portland cement concrete. As previously mentioned, most of the interstate system and about one third of the primary system have PCC surfaces, and since 1954 most have been textured by dragging two separate double thicknesses of burlap on the fresh concrete in the direction that the pavement is being laid.

Wear curves for PCC open highway and stop intersections are shown in Figure 10 and are similar to but closer together than those previously shown for Class I bituminous concrete. After 100,000 axle applications, both open highway and stop intersections have a mean SN of 49 but, as traffic wears the surface, its SN drops slightly faster at intersections (SN 32 @ 30 M) than on open highways (SN 34 @ 30 M).

Likewise, the wear curves comparing traffic and passing lanes, Figure 11, also are similar to but closer together than those previously seen for Class I

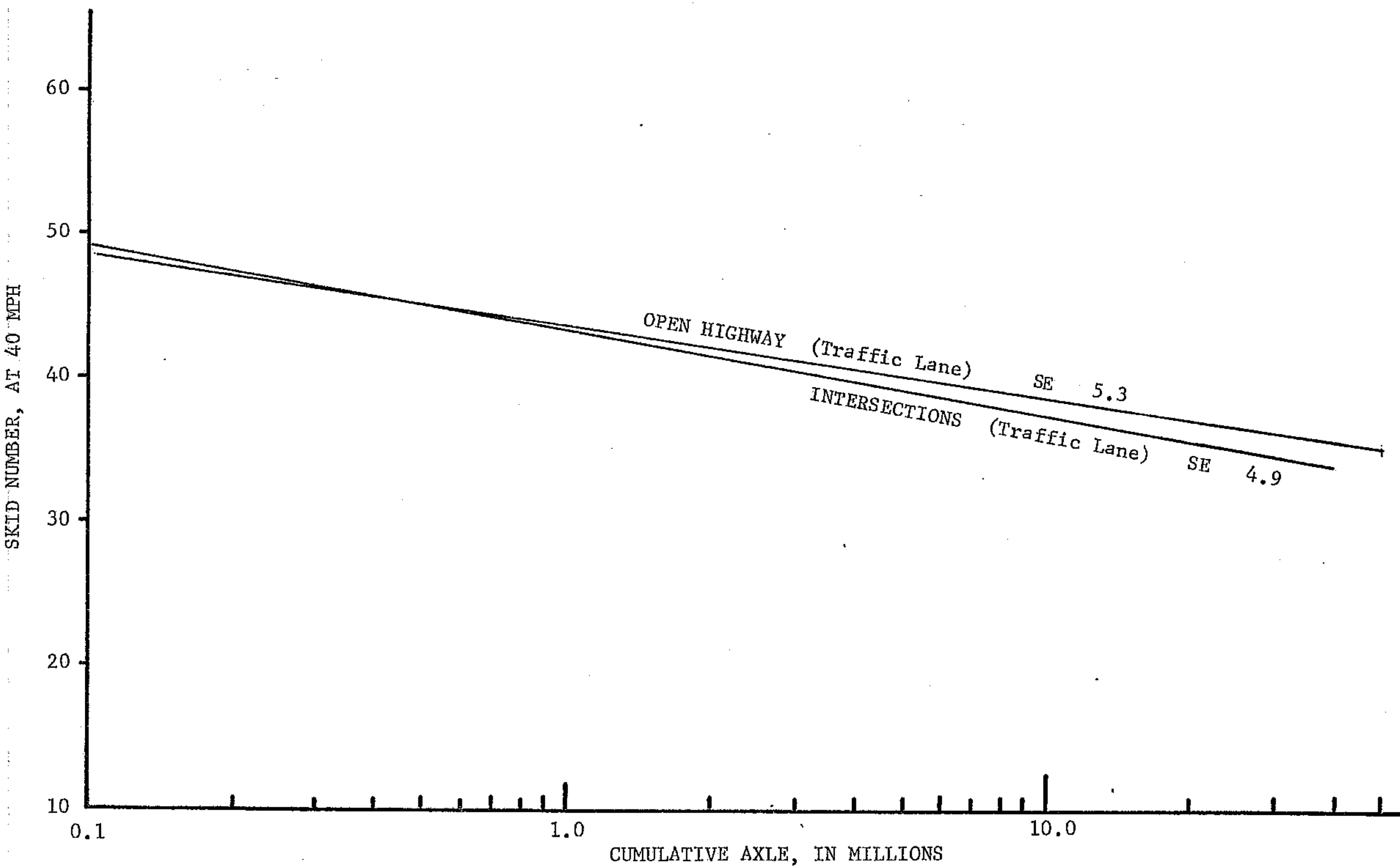


Figure 10. Wear curves for PCC surfaces by location.

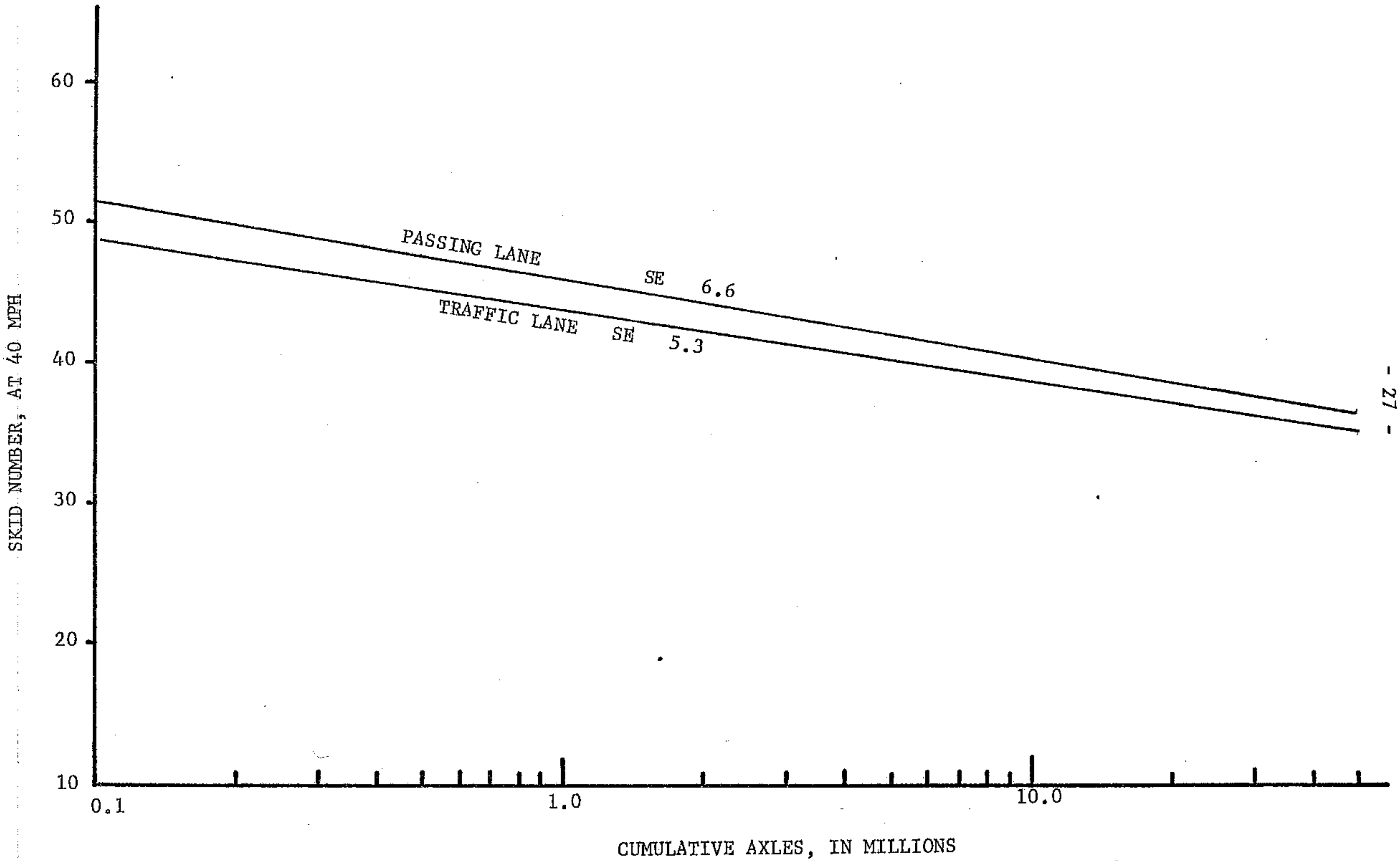


Figure 11. Wear curves for traffic and passing lanes of PCC surfaces.

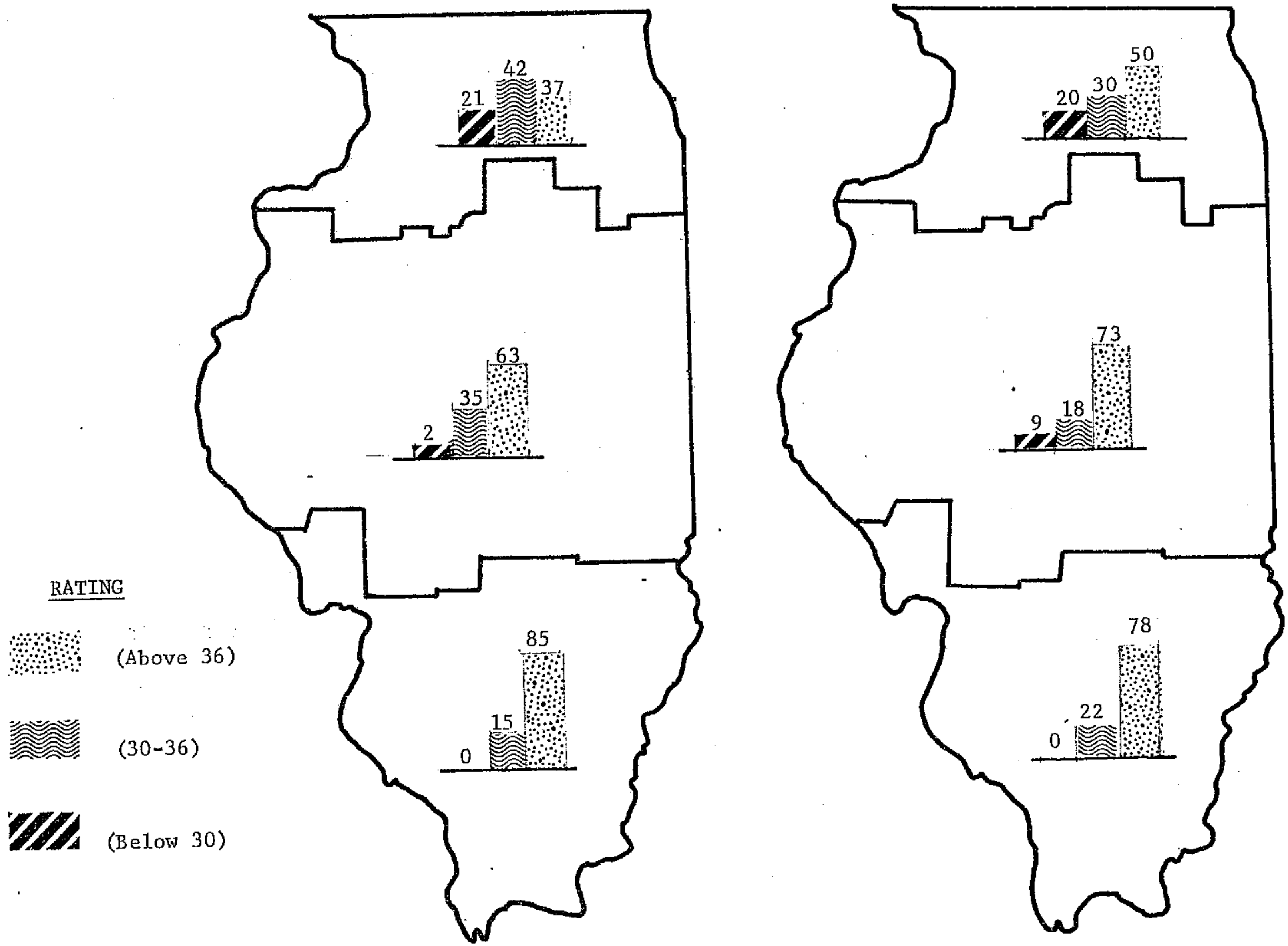
surfaces. In fact, the passing lane wear curve is only 1 to 2 skid numbers above that for the traffic lane.

Next, the mean skid numbers for PCC traffic lanes were grouped into three skid-resistance categories by three geographical areas as was previously done for Class I surfaces. The results of this grouping for open highway are in Figure 12a, while those for stop intersections are in Figure 12b. Again, assuming that the sample of test sites represents the geographical areas, we see in Figure 12a that 21 miles out of 100 miles of PCC open highway in northern Illinois can be expected to have an SN below 30 as compared with 2 miles out of 100 miles for the central part of the State, and with none for southern Illinois.

Similarly, 20 out of 100 PCC stop intersections in northern Illinois can be expected to have an SN below 30 as compared with 9 out of 100 intersections in the central part of the State and none in southern Illinois. This trend, as may be recalled, is the reverse of the trend found for Class I surfaces.

As previously mentioned, texture, which is formed in the fresh concrete mortar surface during final finishing, in addition to good quality concrete is what creates good skid resistance in a PCC surface. Pavement wear, on the other hand, diminishes surface texture in PCC pavements and lowers skid resistance. As an estimate of wear in the three geographical areas, the number of vehicle miles of travel on interstate-primary systems in each area was divided by the mileage of interstate-primary highways in that area to get an average area ADT. As can be seen in Figure 13a, the average ADT in northern Illinois is about three times that of downstate.

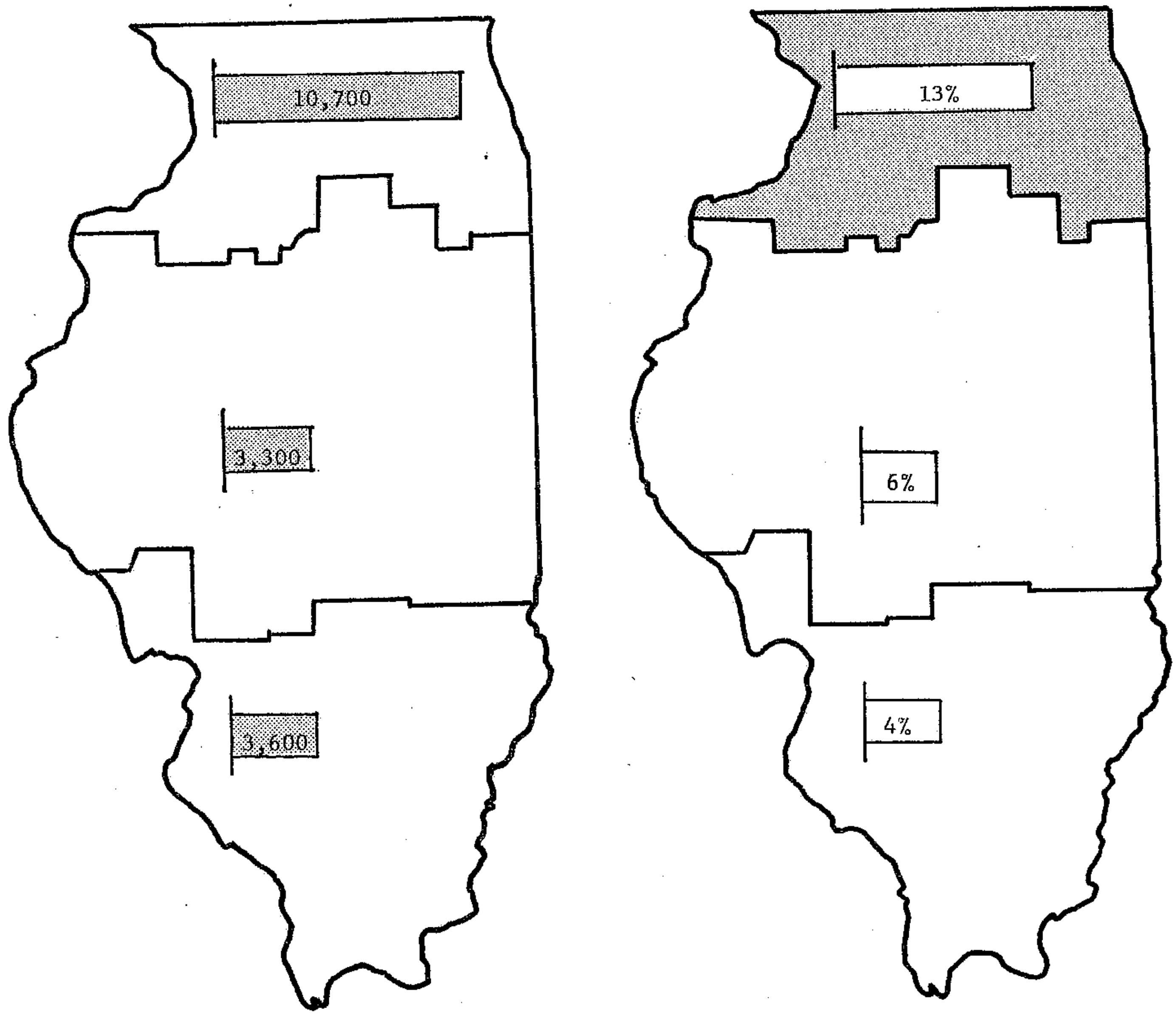
Another equally if not more important fact is that vehicles equipped with studded tires accelerate surface wear. Parking lot surveys conducted annually



(a) Open Highway (Percent of Test Sites)

(b) Intersections (Percent)

Figure 12. Skid resistance rating of PCC surfaces by geographical area.



(a) 1972 Average Daily Traffic

(b) Studded Tire Usage

Figure 13. Geographical distribution of traffic and studded tire usage in Illinois.

throughout Illinois since 1966 indicate that 13 percent of the passenger cars in northern Illinois as compared with 6 percent in the central area and 4 percent in the southern area (Figure 13b) are equipped with studded tires. Higher traffic volumes and more vehicles equipped with studded tires in northern Illinois than downstate logically account for northern Illinois having a mean SN of 34 as compared with a mean SN of 40 downstate. Also, slightly lower studded tire usage in southern than in central Illinois probably contributes to a slightly higher skid resistance in southern than in central Illinois. In fact, laboratory tests have shown that studded tires produce 100 times more abrasive damage than that produced by conventional tires combined with salt and sand (8).

In addition to surface texture, the fine aggregate in newer PCC surfaces is believed to influence skid resistance; accordingly, the shape that sand particles (subangular and round) may have on skid resistance was evaluated. Skid numbers for both traffic and passing lanes having less than 1 million cumulative axle applications were separated by subangular and by round sand particles in the mortar. Relative cumulative frequency distributions by skid number were prepared for both sand particle shapes and are shown in Figure 14a. The resultant curves suggest that skid resistance apparently was unaffected by the shape of sand particles in these surfaces.

To carry this analysis one step further, PCC pavements were analyzed to see what effect, if any, the type of exposed coarse aggregate in the surface might have on skid resistance. Assuming that coarse aggregate may be partly if not completely exposed after 16 million axle applications, skid numbers of traffic lanes were separated by gravel and by crushed stone coarse aggregates. Then, as was done with fine aggregate, relative cumulative frequency distributions by skid

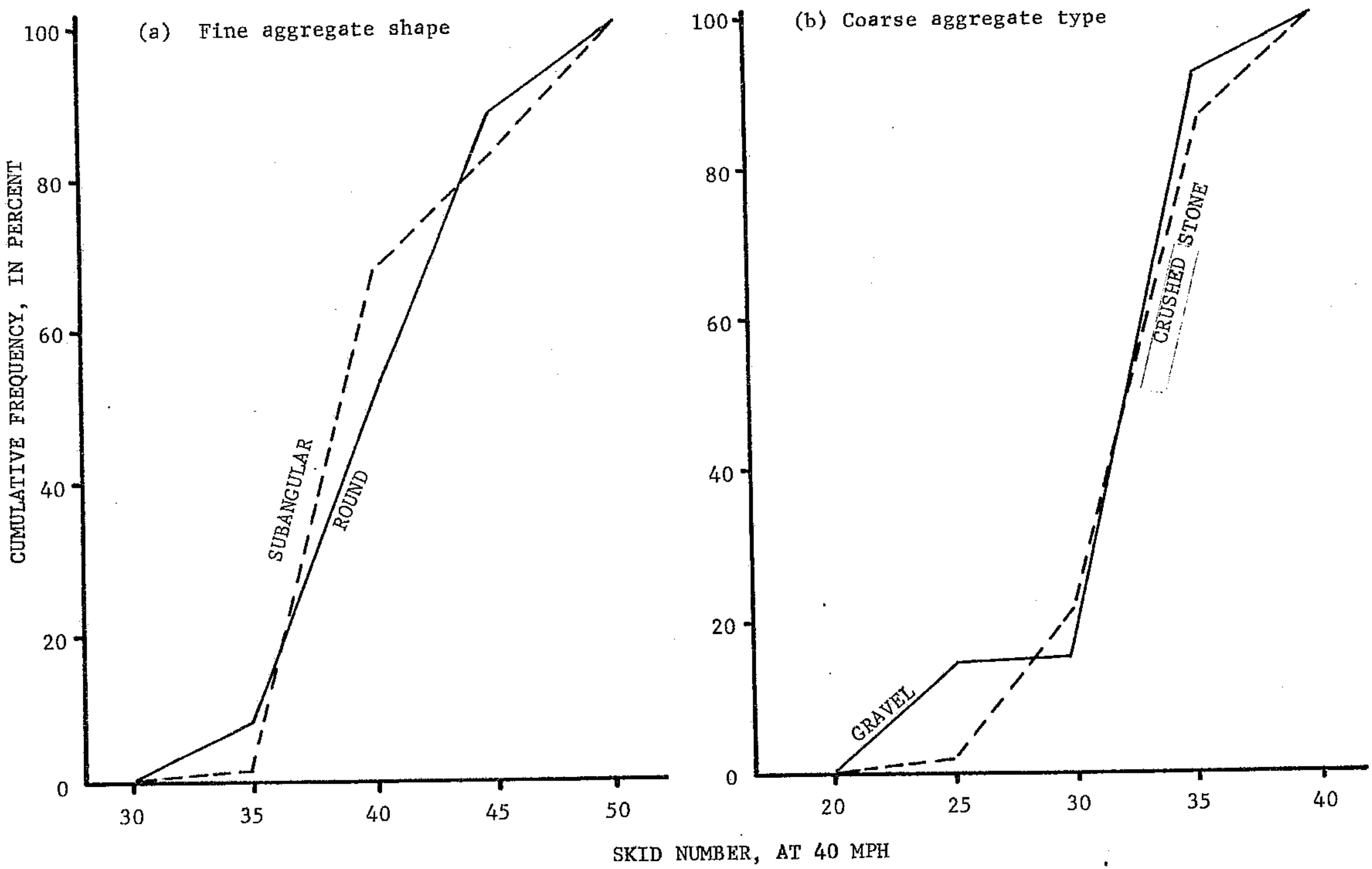


Figure 14. Relative cumulative frequency curves of mean skid number for PCC pavement by shape of fine aggregate and by kind of coarse aggregate.

number were made for both kinds of coarse aggregate and are shown in Figure 14b. Neither the crushed stone nor the gravel curve differed significantly from each other, which suggests that skid resistance was unaffected by the type of coarse aggregate used in portland cement concrete, yet wearing away surface texture and exposing the coarse aggregate in PCC concrete do lower its skid resistance, on the average, about 10 skid numbers.

Age, by itself, is not believed to be an important factor influencing the skid resistance of a PCC pavement; nevertheless, age does interact with axle applications to affect wear. As was done with the Class I bituminous concrete surfaces, both open-highway sites and intersections were sorted into four groups according to cumulative axle applications. Then, mean skid numbers were calculated for and were compared by age at the time of testing. The resulting curves can be seen in Figure 15. Like the Class I curves, some points of the curve vary because one fourth of the points represent only one test site.

Since weathering is believed to have little influence on PCC surfaces, the curves in Figure 15 should have little or no slope; yet, the younger pavements, from age 0 to age 5, have a rather steep upward slope, while those six years and older have a flatter slope. This can be interpreted in two ways - on one hand, the upward slope could indicate weathering enhances skid resistance of PCC surfaces, while on the other hand perhaps some change occurred about 1965-1966, causing pavements 6 years and younger to have a lower SN. The latter assumption is believed more realistic since this was about the time when studded tires began gaining popularity and when paving contractors began changing to the slipform from the side form method of paving, which affected surface texture.

The usage of studded tires really was insignificant until 1968 (age 2), but since that time studded tire wear has been evident, particularly on interstate

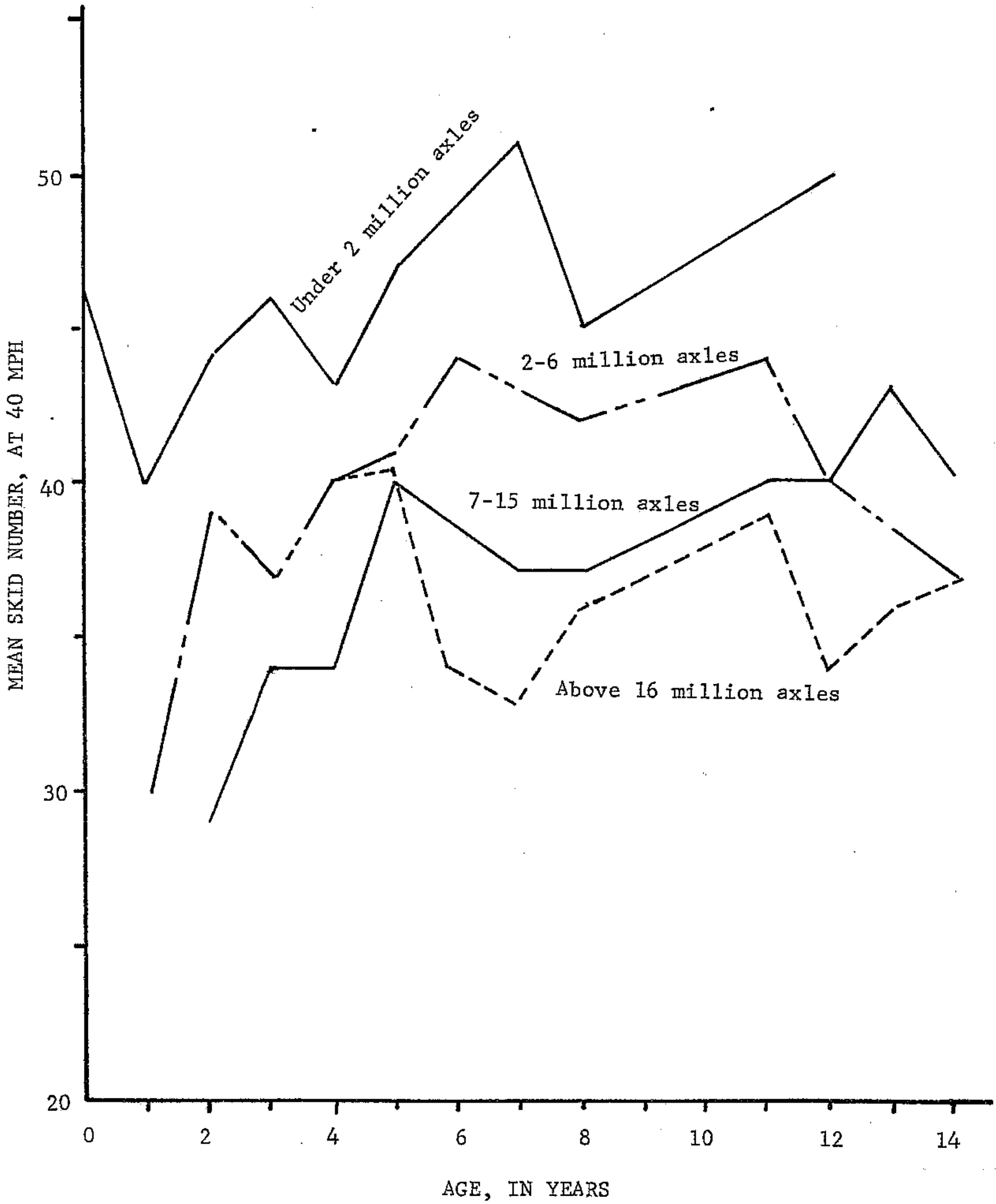


Figure 15. Change in skid number of PCC pavements with age.

and primary highways in northern Illinois, and undoubtedly has contributed to lowering the skid resistance of PCC surfaces.

In addition to studded tire wear, the original surface texture of some of the earlier pavements placed by slipform pavers was believed less than that previously attained when the pavement was placed by pavers riding on side forms. Prior to slipform paving, final finish was achieved by the use of two separate, double-thickness, burlap drags at least 4 ft wide and 2 ft longer than the width of the slab being constructed. When slipform paving first became popular, contractors usually attached a burlap drag directly to the trailing slipform behind the paver, and texturing was obtained with a single pass of the drag. Frequently, the drag passed over the fresh mortar surface at a time when the consistency of the fresh concrete surface was such that less than optimum texture was achieved. Because of a noticeable reduction in surface texture with the single pass of the burlap drag, the standard specifications were again revised in 1968 and reverted to requiring two passes with the burlap drag.

Bituminous vs Portland Cement Concrete Surfaces

Having analyzed Class I and PCC surfaces separately, they are combined now and compared in Figure 16 for open highway and in Figure 17 for intersections. Looking first at open-highway sites (Figure 16), the wear curve for PCC sites, for all practical purposes, coincides with that for Class I dolomite, while the curve for Class I gravel is flatter and crosses the PCC curve at about 3 million axle applications and the curve for Class I limestone is well below the PCC and other curves. In fact, after 50 million axle applications, the PCC and the Class I dolomite curves still have a mean SN of 35, while the Class I limestone curve reaches a mean SN of 35 after only 0.6 million axle applications.

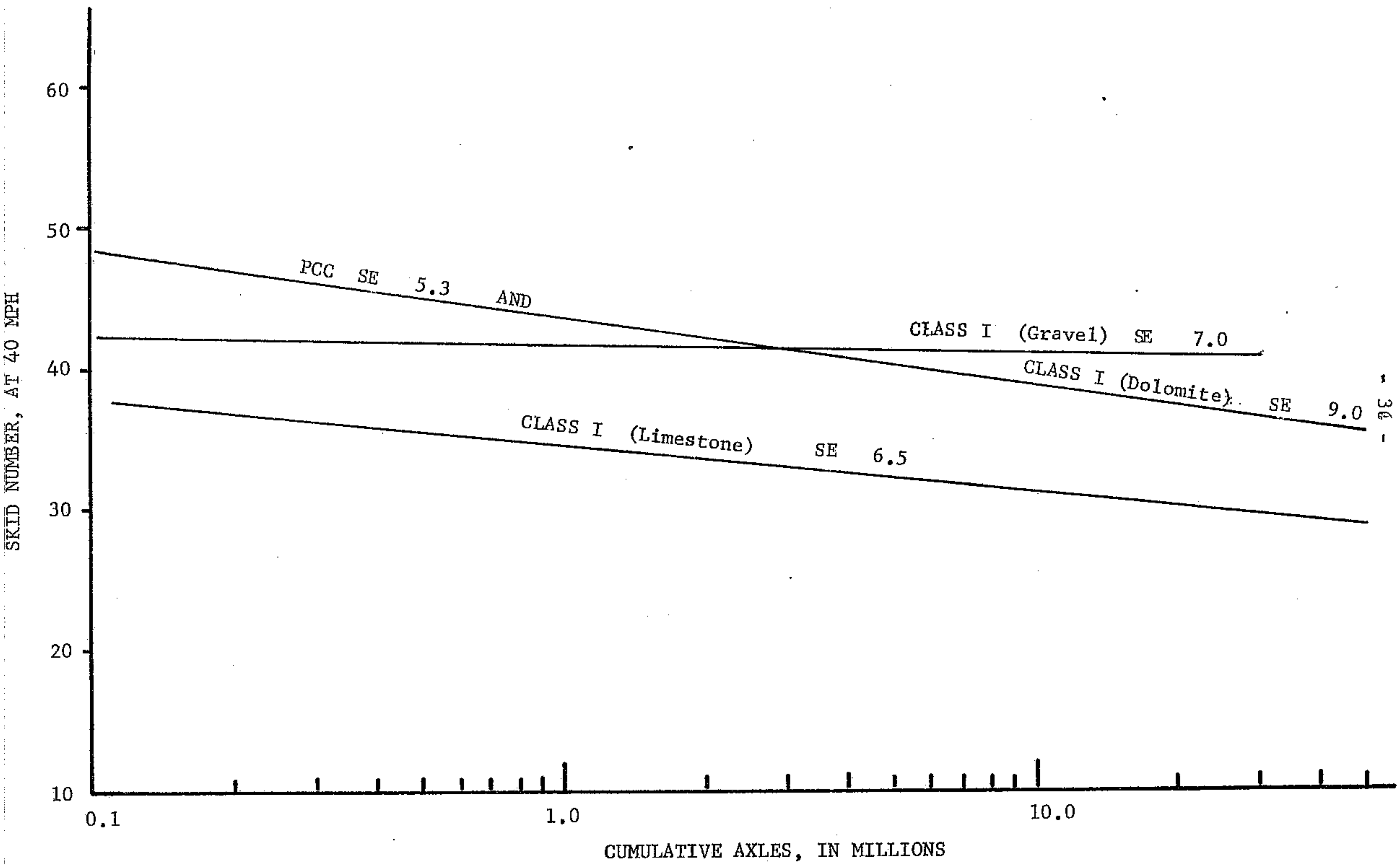


Figure 16. Comparison of wear curves for traffic lanes on open highway by type of surface.

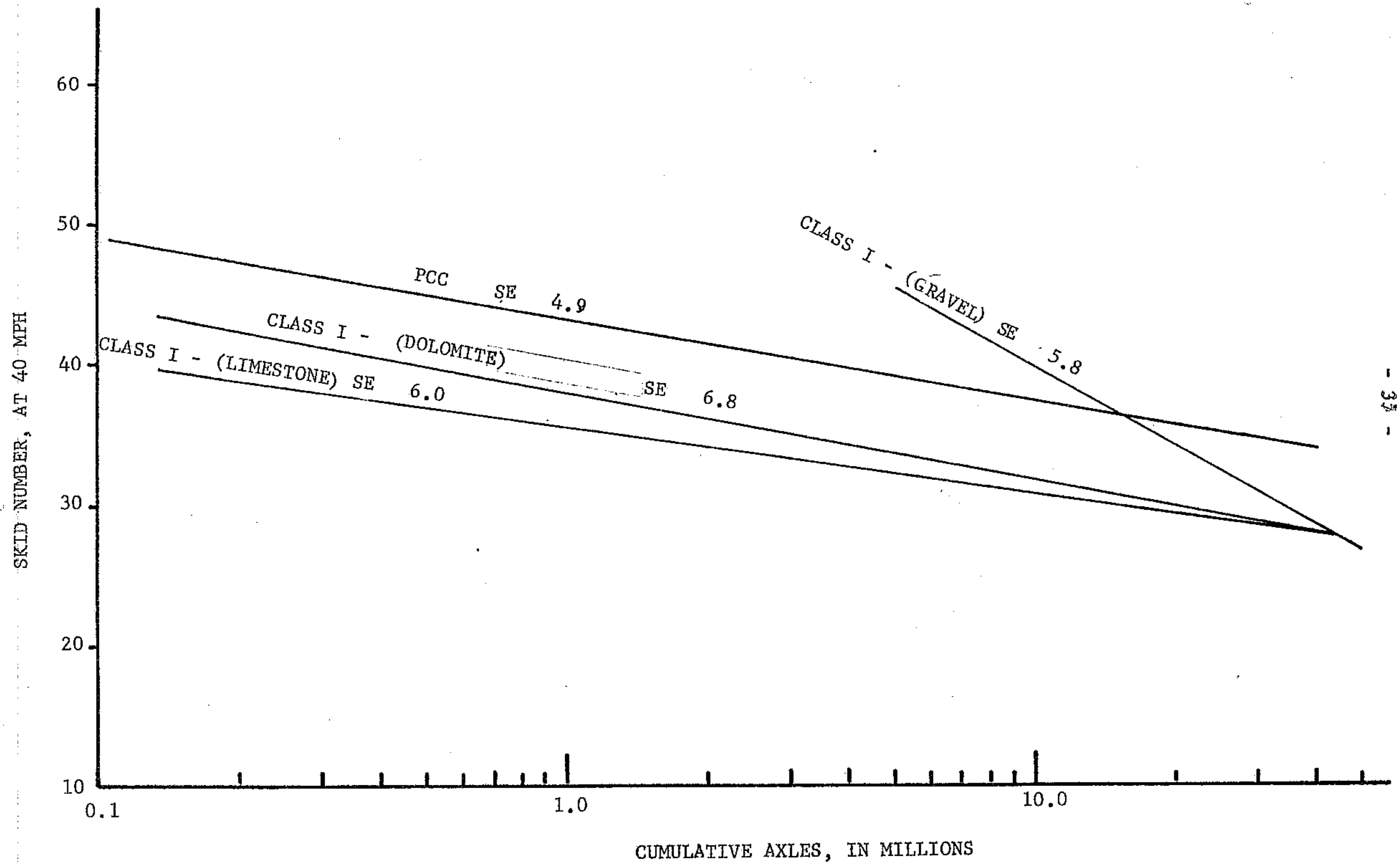


Figure 17. Comparison of wear curves for traffic lanes at intersections by type of surfaces.

Now, turning to intersections in Figure 17, here the wear curve for PCC surfaces generally maintains a skid number above 36, which is well above the SN for Class I surfaces regardless of whether crushed stone or gravel coarse aggregate was used. In addition to the general lower level of skid resistance, intersections having Class I surfaces containing dolomite and crushed gravel aggregate lose their skid resistance at a faster rate than PCC surfaces, mainly because bituminous surfaces, as previously mentioned, lose their surface texture at intersections. Another interesting comparison between Class I wear curves and PCC wear curves is that the standard error of estimate for Class I open-highway sites and intersections varies more widely than that for PCC wear curves.

Anticipated Skid Life to SN 35

In the preceding analysis, Class I surfaces in southern Illinois and PCC surfaces in northern Illinois generally had lower skid numbers than similar surfaces in the rest of the State. To determine the anticipated skid life of these pavements, wear curves (traffic lane) for both types of surfaces were calculated by geographical area and are shown in Figure 18. Class I pavements after 100,000 axle applications have a mean SN of 46. As they are worn, those in southern Illinois drop to a mean SN of 35 after only 2.1 million axle applications, primarily because they contain soft limestone which wears and polishes easily, but those in northern and central Illinois take 78 and 112 million axle applications respectively to reach the same skid level because they contain dolomite and gravel, which are harder than limestone. On the other hand, PCC pavements have a mean SN of 50 after 100,000 axle applications. After 44 million axle applications, PCC pavements in central and southern Illinois approach a mean SN of 35 and 39, respectively. PCC surfaces in northern Illinois, however, approach a mean SN of

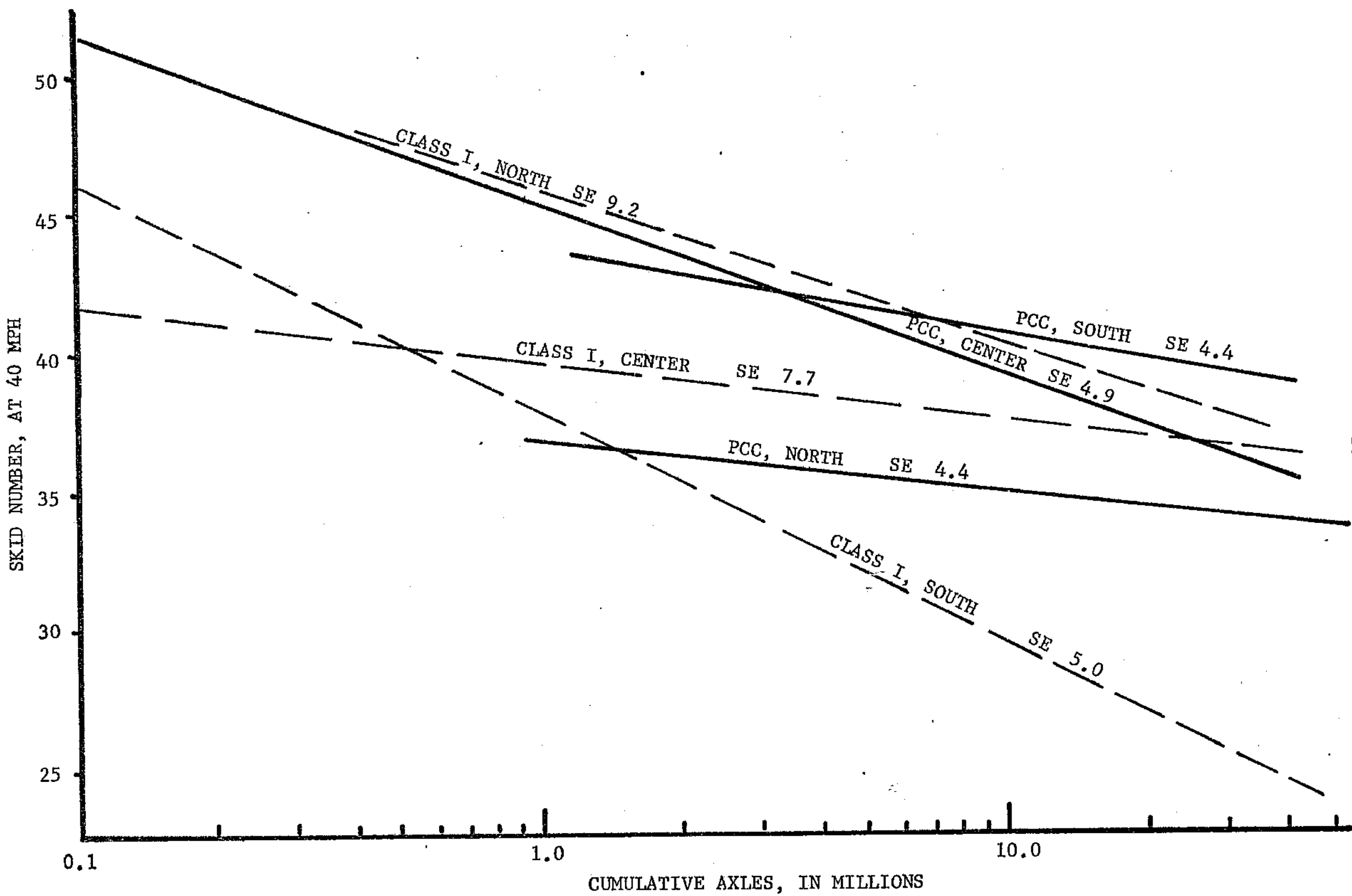


Figure 18. Wear Curves for PCC and Class I surfaces by geographical area.

35 after only 7.3 million axle applications. This lower value is attributed mainly to greater use of studded tires in northern Illinois than downstate. The cumulative axle applications obtained from these curves can be used with actual and estimated traffic volumes to predict how long, on the average, a particular kind of surface should maintain a skid number above 35.

For the past several years, the Statewide average distribution of vehicle types within the traffic stream - passenger cars, single-unit trucks, and multi-unit trucks - has remained fairly constant on primary and interstate routes. On rural interstate routes during 1972, for example, passenger cars (2.0 axles) accounted for 74 percent, single-unit trucks (2.1 axles) 9 percent, and multi-unit truck combinations (4.8 axles) 17 percent of the traffic stream, while on primary routes that same year passenger cars (2.0 axles) accounted for 78 percent, single-unit trucks (2.1 axles) 16 percent, and multi-unit truck combinations (4.8 axles) 6 percent of the total traffic stream.

Knowing the distribution of vehicles in the traffic stream as well as their distribution in the design (outside traffic) lane, Table 2, the number of axle applications per lane per year can be computed for any type of highway; then, the mean age, in years, when a particular surface is expected to reach an SN of 35 can be calculated by dividing the number of cumulative axle applications obtained from the wear curve for that particular surface by the number of axle applications per lane per year passing over that surface. To illustrate this, the mean anticipated skid life of both PCC and Class I surfaces to an SN of 35 has been calculated for a range of ADT volumes on two-lane, four-lane, and six-lane highways, and is presented in Table 3. The outside traffic lanes of multi-lane highways, in Table 3, are assumed to receive the most wear and to have a lower SN than inner

TABLE 2

AVERAGE LANE DISTRIBUTION OF AVERAGE DAILY TRAFFIC

No. Lanes	Design Lane Traffic, in Percent	
	Passenger Cars	Trucks
2	50	50
4	32	45
6	8	37

TABLE 3

ANTICIPATED SKID LIFE OF INTERSTATE-PRIMARY HIGHWAYS AT AN SN OF 35

ADT	Mean Skid Life, In Years					
	PCC			Class I		
	North	Central	South	North	Central	South
			Two-Lane Highways			
1,000	18	20+	20+	15+	15+	5
2,500	7	20+	20+	15+	15+	2
3,000	6	20+	20+	15+	15+	1
4,000	5	20+	20+	15+	15+	1
5,000	4	20+	20+	15+	15+	1
6,000	3	19	20+	15+	15+	1
			Four-Lane Highways			
5,000	4	20+	20+	15+	15+	2
10,000	2	12	20+	15+	15+	1
15,000	1	9	20+	15	15+	0
20,000	1	6	20+	12	15+	0
25,000	0	5	20+	9	15+	0
30,000	0	4	20+	8	15+	0
35,000	0	4	20+	7	15	0
40,000	0	3	20+	6	14	0
			Six-Lane Highways			
20,000	2	15	20+	15+	15+	1
25,000	2	12	20+	15+	15+	0
30,000	1	10	20+	15+	15+	0
40,000	1	8	20+	14	15+	0
50,000	1	6	20+	11	15	0
60,000	0	5	20+	9	13	0
80,000	0	4	20+	7	10	0
100,000	0	3	20+	6	8	0

traffic lanes. When one lane of a multi-lane highway has a low SN, corrective measures usually are applied to all lanes so that new hazards are not created.

First, looking at portland cement concrete surfaces in the table, most two-lane highways and many of the multi-lane highways in central and southern Illinois should maintain a mean skid number well above 35 most of their 20-year design life. Some of the more heavily traveled multi-lane routes in central Illinois, however, can be expected to have an SN less than 35 before the end of their 20-year design life. On the other hand, the analysis indicates that nearly all of the two-lane and the multi-lane highways constructed of portland cement concrete in northern Illinois, particularly in and around Chicago, can be expected to have skid numbers less than 35 appreciably before the end of their 20-year design life. As previously mentioned, greater usage of studded snow tires in northern Illinois than downstate probably accounts for the early loss of skid resistance in PCC pavement in northern Illinois.

As for Class I surfaces, a majority of two-lane highways in central and northern Illinois should maintain an SN above 35 most of their 15-year design life, but heavily traveled multi-lane routes, particularly those in the Chicago area, can be expected to drop below an SN of 35 before 15 years.

Unless the ADT is less than 1,000 vpd, the analysis indicates that most Class I surfaces in southern Illinois can be expected to have an SN below 35 considerably before the end of the 15-year design period. This is due primarily to the predominant use of soft limestone coarse aggregate in the mixture. The predominant use of crushed limestone coarse aggregate in Class I surfaces in southern Illinois is dictated by the availability of materials. As previously shown in Figure 6, practically all aggregate sources in this part of the State are limestone.

RESULTS - COUNTY HIGHWAY SYSTEM

Over 16,000 miles of highways in Illinois are designated as County Highways, most of which are low-volume, farm-to-market roads. Their surfaces vary from portland cement concrete to gravel and oiled earth. However, the surface of many County highways today is either a bituminous concrete mat or a bituminous surface treatment.

Of the 115 County highway sites previously referred to in Table 1, 40 sites (26 open-highway and 14 intersections) were Class B bituminous concrete and 75 sites (45 open-highway and 30 intersections) were Class A bituminous surface treatments.

In this section, skid-resistant characteristics of Class B bituminous concrete surfaces will be described first, followed by Class A bituminous surface treatments. Then, their anticipated skid life will be discussed.

Class B; Bituminous Concrete Surfaces

Class B bituminous concrete serves mainly as a surface course overlying a flexible base. Because the base is flexible rather than rigid, the asphalt cement used in the surface is softer than that used in Class I mixtures. Also, larger top size (1 1/2 in.) and lower-quality aggregate are allowed in Class B mixtures than are permitted in Class I mixtures, and gradation control is not as stringent.

Wear curves calculated for open-highway sites and intersections (Figure 19) indicate that the skid resistance at intersections is lower than that along the open highway, which is similar to the finding for Class I surfaces. Class B surfaces, after 4 million axle applications, drop to a mean SN of 33 for open highway and to a mean SN of 31 for intersections from a mean SN of 50 at 100,000 axle applications. Had some sites carrying more traffic over a longer period of

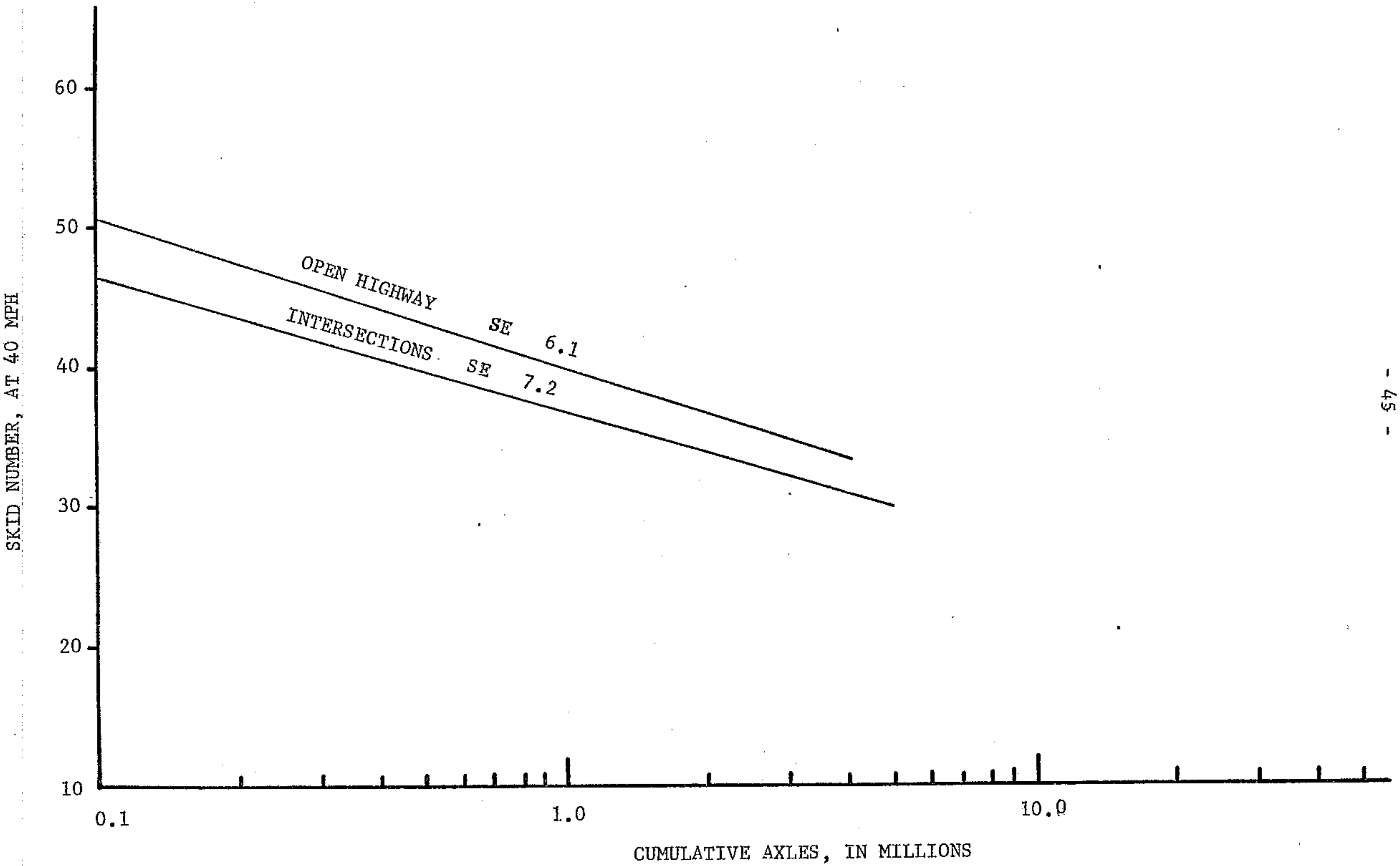


Figure 19. Wear curves for Class B bituminous concrete surfaces by location.

time been tested, the slope of these curves probably would have been slightly flatter than they are because their SN probably still would be in the low 30's.

Open-highway sites and intersections were grouped by their mean SN into the three previously described skid resistance levels. The sites were not arranged geographically as were the PCC and the Class I surfaces because only five of the nine districts supplied test sites; nevertheless, the ones that were selected are scattered fairly well between northern and southern Illinois. The results of this grouping for both open-highway sites and intersections are in Table 4. Assuming that this smaller sample does represent the entire State, the skid tests indicate that 84 miles out of 100 miles of open highway should have an SN above 36, while only 12 miles out of 100 miles should have an SN below 30. Correspondingly, intersections have a similar but lower trend. Here, 65 out of 100 intersections have an SN above 36, whereas 21 out of 100 intersections have an SN below 30, leaving 14 out of 100 intersections with an SN between 30 and 36.

Although a complete analysis by aggregate type was impractical, the skid resistance of Class B surfaces, like Class I surfaces, is assumed to change with the kind of coarse aggregate used in the mix. To check this assumption, relative cumulative frequency curves were prepared for surfaces containing crushed stone (both limestone and dolomite) and gravel coarse aggregate, and are shown in Figure 20. Dolomite was not separated from limestone because the sample was too small. The resulting crushed stone curves have lower skid numbers than the gravel curves, which reinforces a previous finding. In fact, all of the sites having a skid resistance below 30 and a majority of the sites having a skid resistance between 30 and 36 contained crushed stone coarse aggregate. Having established this difference, a corresponding set of wear curves was calculated and is shown

TABLE 4

SKID RESISTANCE RATING OF CLASS B, BITUMINOUS CONCRETE SURFACES

Location	Percent of Total Sites with SN		
	Below 30	30-36	Above 36
Open highway	12	4	84
Stop intersection	21	14	65

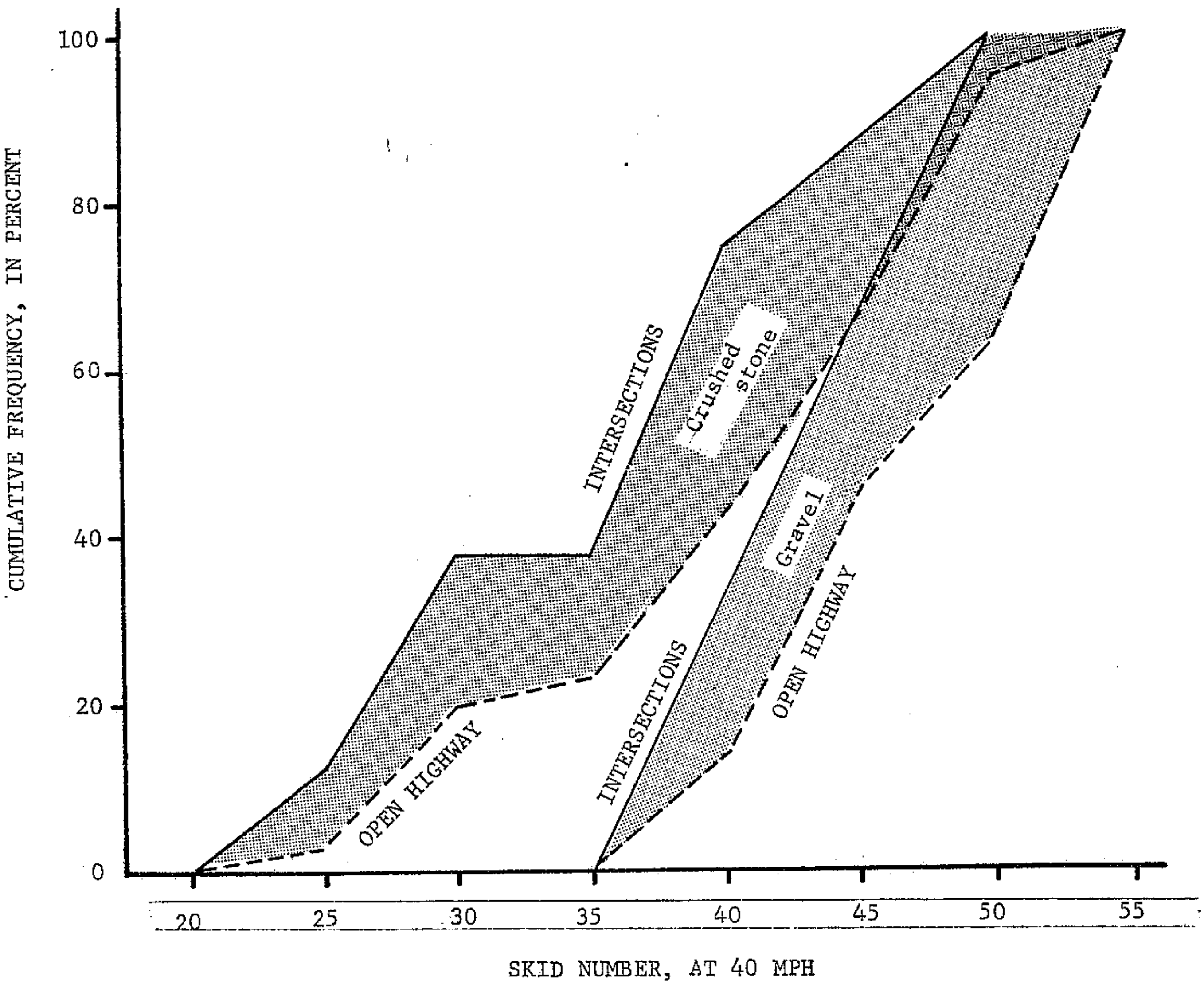


Figure 20. Relative cumulative frequency curves for Class B bituminous concrete by location and aggregate type.

in Figure 21. The arrangement of these curves resembles those for Class I surfaces, which suggests that both behave similarly.

Pavement age, which apparently influences the skid resistance of bituminous surfaces, also was analyzed for Class B surfaces. Open-highway sites and intersections were combined and sorted into three groups according to cumulative axle applications - under 0.5 million, 0.5 to 1.5 million, and over 1.5 million. Mean skid numbers, for traffic lanes, were then calculated by age at the time of testing, and the resulting curves are shown in Figure 22. Except for age 2 and age 4 in the lowest curve, the points along the curves represent an average of from 2 to 9 sites. The under 0.5 million axle curve is relatively flat at an SN near 47, but both the 0.5 to 1.5 million and the over 1.5 million axle curves have distinct upward slopes. This upward trend of the two lower curves suggests that weathering affects the rate of change in SN of a bituminous concrete surface. Looking at the 0.5 to 1.5 million axle curve, for example, a two-lane pavement, two years old, has a mean SN of 31, while a surface seven years old has a mean SN of 46, which is a difference of 15 skid numbers.

Class A, Bituminous Surface Treatments

Bituminous surface treatments in Illinois comprise one or more layers of asphalt and seal coat aggregate. Well-designed and constructed bituminous surface treatments can provide not only dustless all-weather surfaces but also good skid-resistant surfaces. In fact, new surface treatments often have more macroroughness than Class I and Class B bituminous concrete surfaces, but their skid resistance in Illinois varies widely. Surface treatments are extremely sensitive to certain construction procedures which, when improperly executed, can render a surface partly or entirely slippery when wet. Sometimes the entire surface may

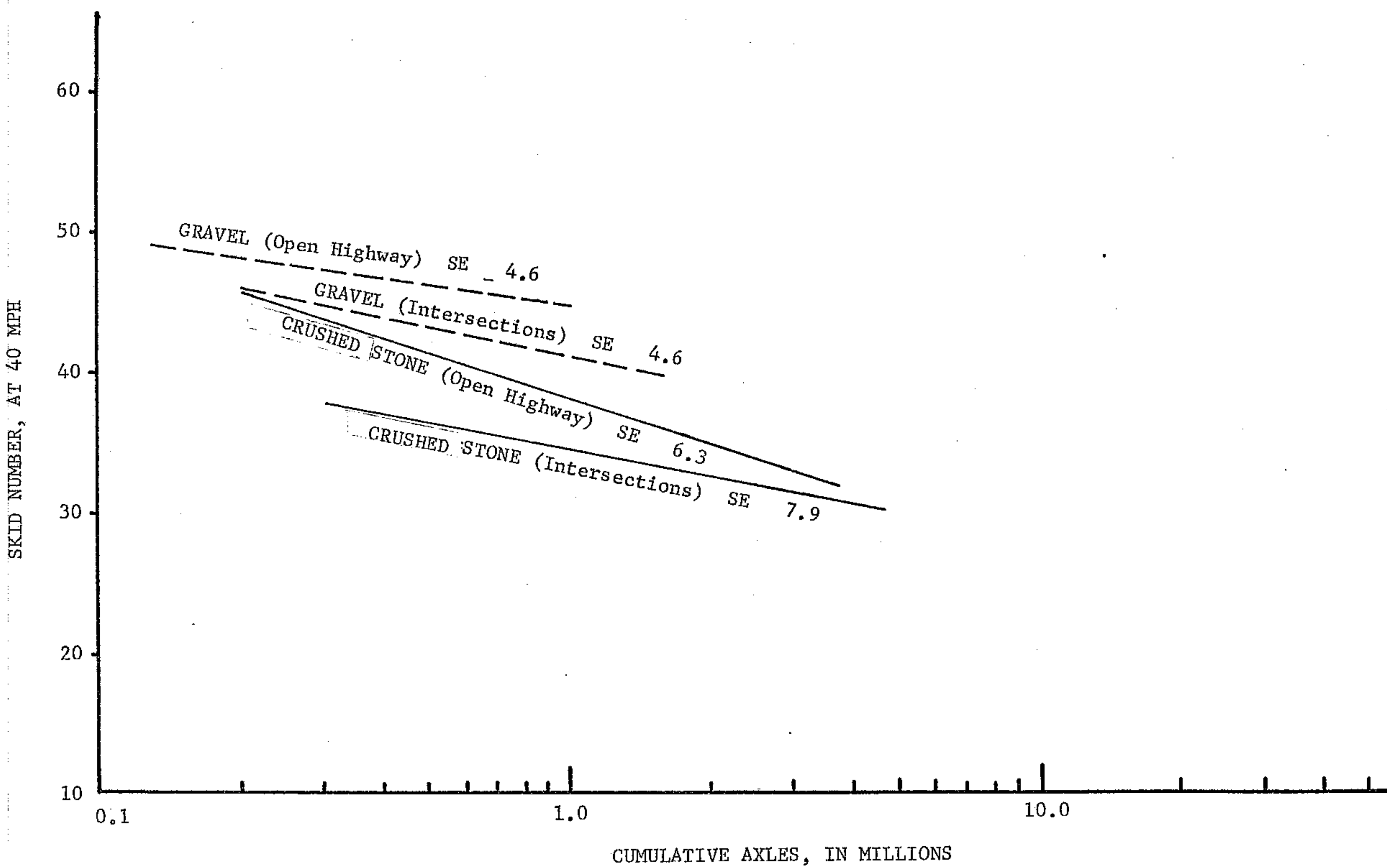


Figure 21. Wear curves for Class B bituminous concrete surfaces by location and by aggregate type.

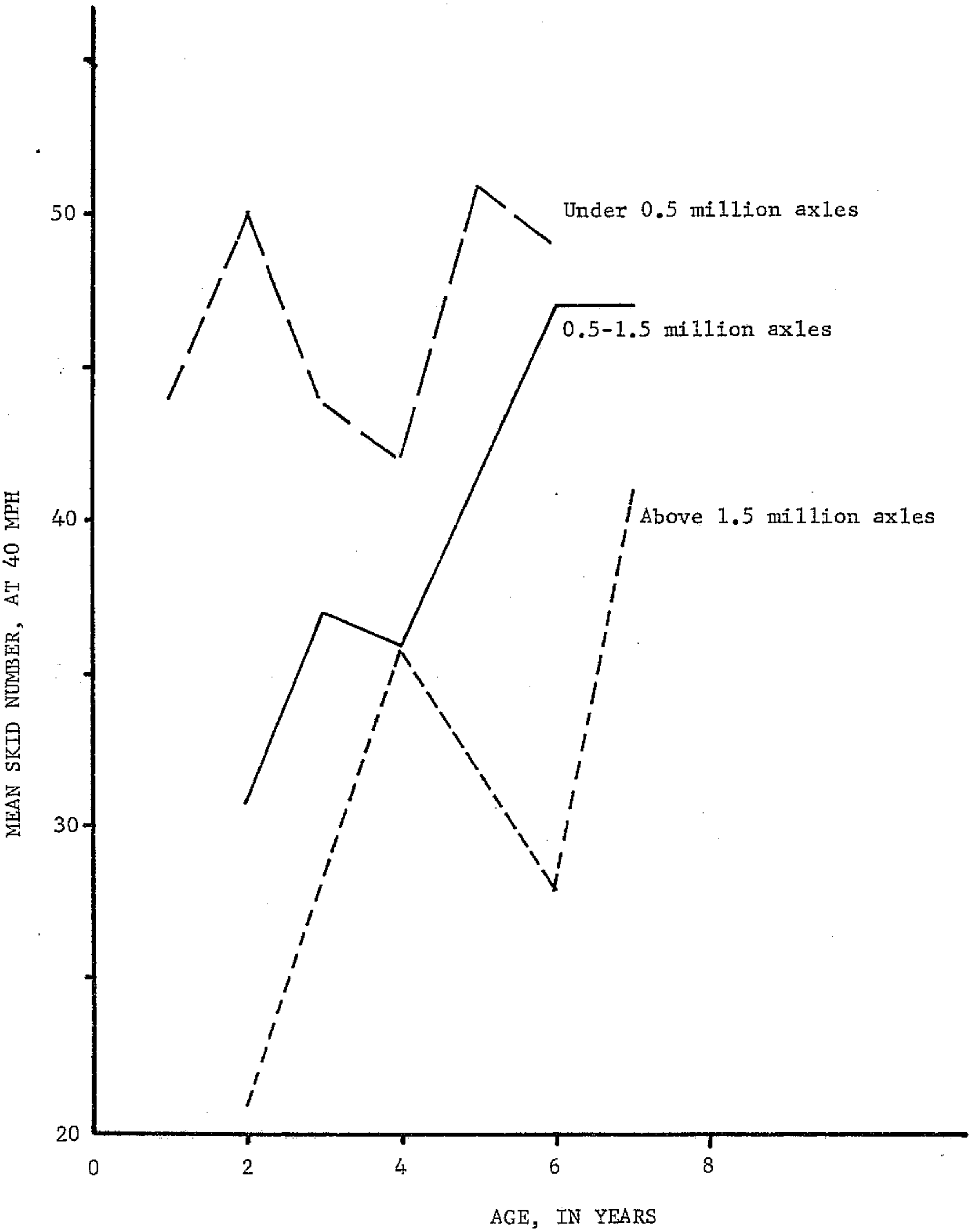


Figure 22. Change in skid number of Class B bituminous concrete surfaces with age.

have a skid number in the low teens, while other times it may vary from the low teens to the high 50's within a project as well as among projects.

Of the 75 bituminous surface treatment sites tested, 45 are open-highway sites and 30 are intersections. Moreover, stone chips and pea gravel, which are the commonly used aggregates, are distributed about equally among the sites. Even though three Districts in the northern half of the State did not select sites, those selected are scattered from northern to southern Illinois.

Wear curves for highway sites and intersections, in Figure 23, indicate that the mean SN of a Class A surface after 100,000 axle applications is approximately 38. The high standard error of estimate (9.8) reflects a wide variability in skid resistance among sites, which seems to be characteristic of many Class A surfaces in Illinois. After 1.4 million axle applications, the mean SN along the highway drops to 31, as compared with 24 at intersections. The wide variability in skid resistance of Class A surface treatments is not surprising, considering the skill involved in proper construction. The correct amount of asphalt and proper aggregate embedment will result in a good seal coat. Too little asphalt or aggregate embedment will result in loss of aggregate, and too much asphalt or aggregate embedment will result in surface bleeding, both of which can result in a slick surface with low skid resistance.

Again, the sites were grouped into the three skid resistance categories mentioned previously, by location and by aggregate type. No attempt was made to analyze them geographically because of sample bias. Assuming that these groupings, which are in Table 5, represent the entire mileage of Class A surface treatments in Illinois, they indicate that 45 miles out of 100 miles of open highway and 24 out of 100 intersections would have an SN above 36. On the other hand, 33 miles

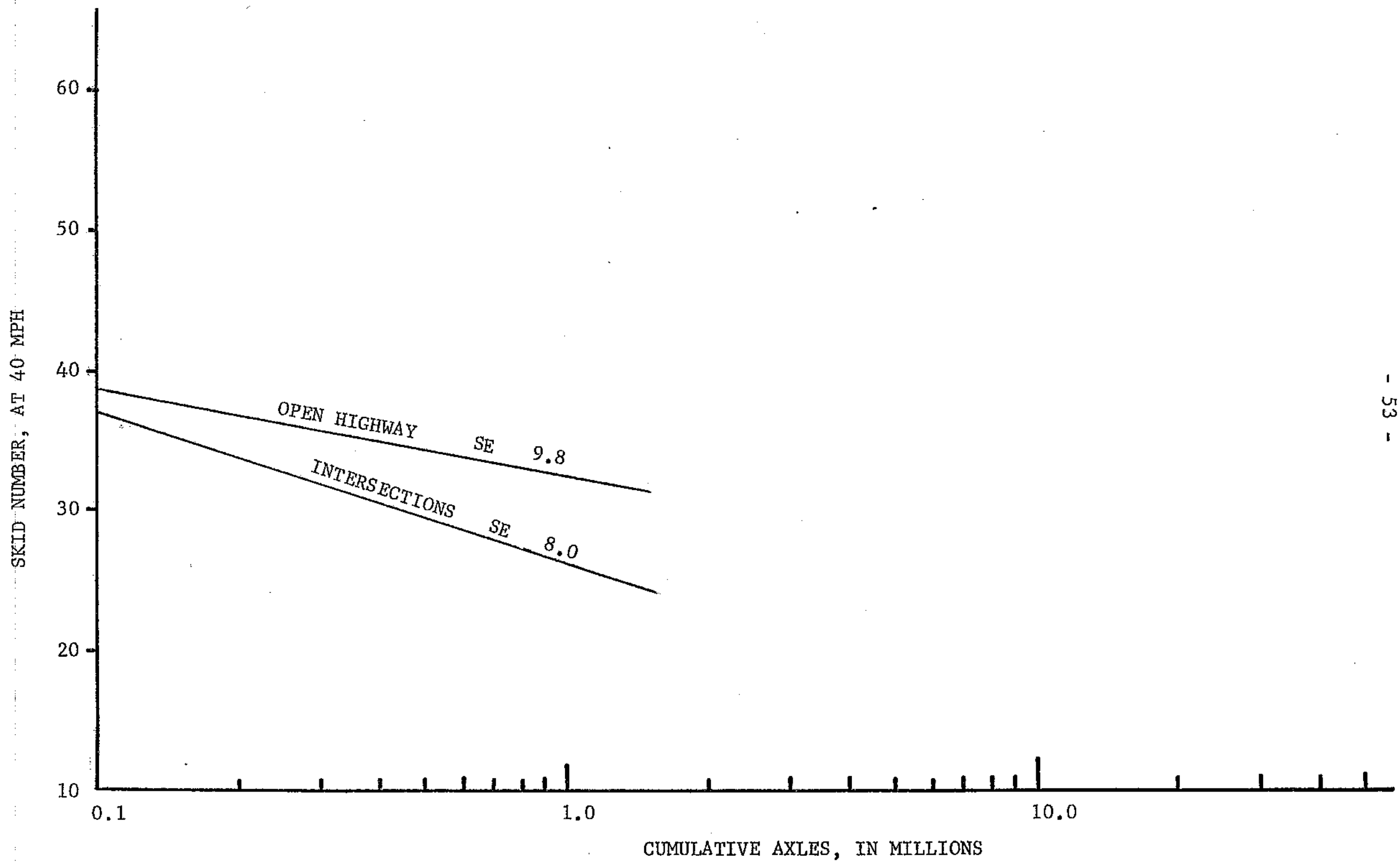


Figure 23. Wear curves for Class A bituminous surface treatments by location.

TABLE 5

SKID RESISTANCE RATING OF CLASS A, BITUMINOUS SURFACE TREATMENTS

Location	Aggregate Type	Percent of Total Sites with SN Below 30	30-36	Above 30	Total
Open highway	Gravel	9	11	25	45
	Crushed stone	24	11	20	55
	All	33	22	45	100
Intersection	Gravel	20	10	17	47
	Crushed stone	36	10	7	53
	All	56	20	24	100

out of 100 miles of open highway and 56 out of 100 intersections would have an SN below 30. Of the sites having an SN above 36, five out of nine highway sites and two out of three intersections had pea gravel as their seal coat aggregate. Conversely, of the sites having an SN below 30, three out of four highway sites and two out of three intersections had stone chips as their cover coat aggregate. The fact that crushed stone more than gravel aggregate is associated with low skid resistance again reinforces the need for hard nonpolishing aggregates to maintain satisfactory skid-resistant surfaces.

The effect age has on skid resistance of Class A bituminous surface treatments was examined by sorting the sites into three groups according to total cumulative axle applications - under 0.1 million applications, 0.1 to 0.5 million applications, and over 0.5 million applications. Mean skid numbers were calculated by age at time of testing and plotted in Figure 24. No significant trends exist, which suggests that weathering has little influence on the skid resistance of bituminous surface treatments. This could be due partly to the wide variability that exists in SN and partly to the very short service lives surface treatment generally have before being resealed.

Anticipated Skid Life to SN 35

Although a geographical difference in skid resistance no doubt exists in Class B bituminous concrete surfaces and Class A surface treatments as they do in Class I surfaces, insufficient tests were obtained from which wear curves could be determined for each geographical area. Therefore, computing the anticipated skid life of these surfaces will be limited to the wear curves (traffic lane) calculated from all open-highway sites regardless of aggregate type. Referring to Figure 19, Class B surfaces after 100,000 axle applications have a mean SN near

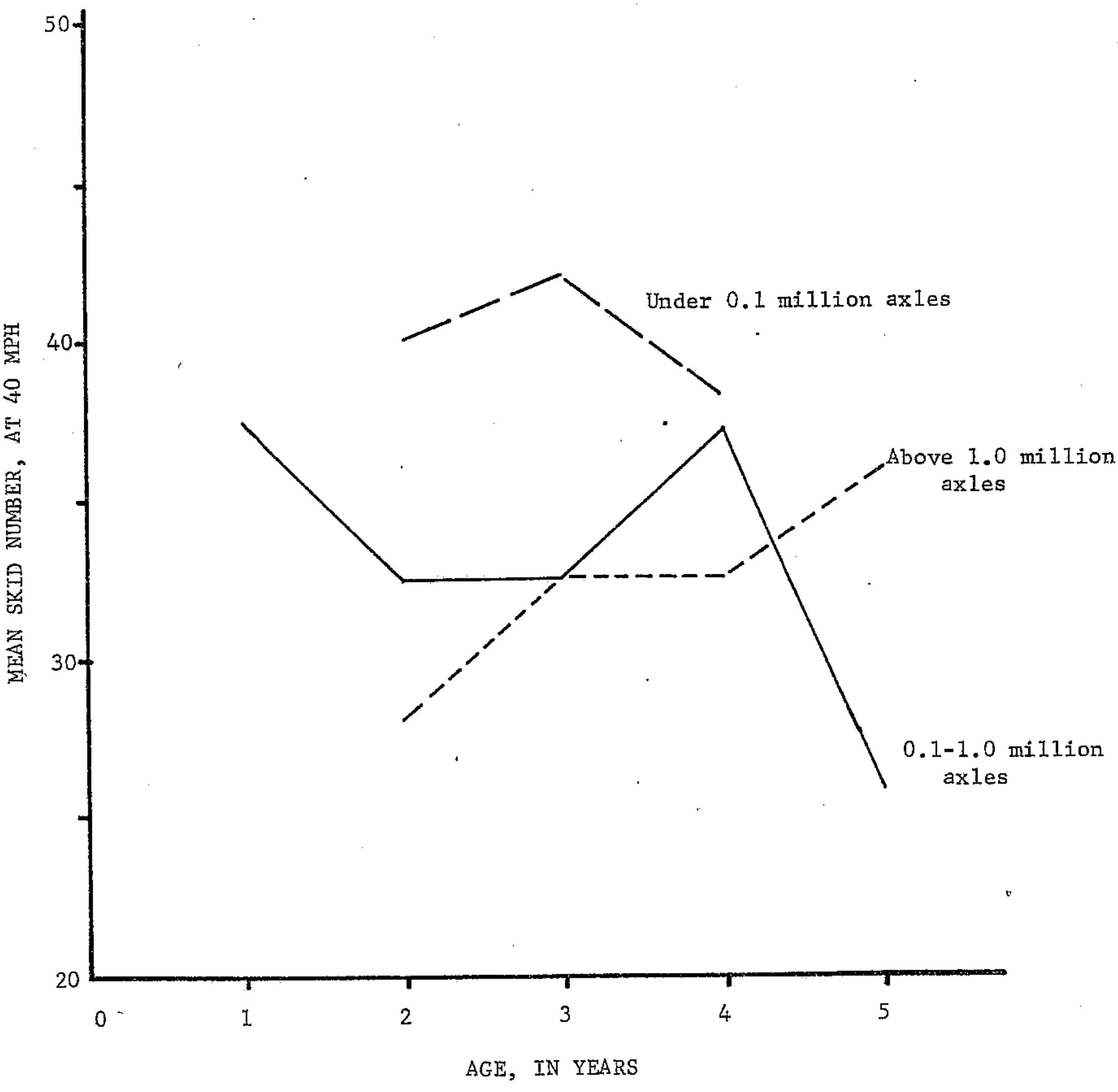


Figure 24. Change in skid resistance of Class A bituminous surface treatments with age.

50, and after 2.7 million axle applications, they drop to an SN of 35. However, those surfaces containing crushed stone, in Figure 21, reached an SN of 35 after only 1.8 million axle applications, while those containing gravel required about 65 million axle applications to reach the same level.

Class A surface treatments, on the other hand, begin with a lower mean skid resistance (SN 38) than Class B surfaces, and have a higher standard error of estimate (9.8) than Class B surfaces (6.1). Moreover, they reach a mean SN of 35 after only 0.37 million axle applications.

Vehicle classification counts taken on a number of County highways in 1972 indicate that the average traffic stream comprises 90 percent passenger cars (2.0 axles), 8 percent single-unit trucks (2.1 axles), and 2 percent multi-unit trucks (4.8 axles).

Using the preceding information, the anticipated skid life of Class B and Class A surfaces was computed as previously explained and is presented in Table 6. Looking first at Class B surfaces, they should maintain a mean SN above 35 most of their 15-year design life as long as the ADT does not exceed 500. This will cover a major portion (80 percent) of the mileage of secondary and local roads. Because the curves represent surfaces containing all kinds of aggregates, the estimated skid life is believed conservative for those surfaces containing gravel, and slightly optimistic for those surfaces containing crushed stone. Using the wear curves in Figure 21, most Class B surfaces containing gravel and carrying less than 1000 vpd can be expected to maintain an SN above 40 throughout most of their 15-year design life, but those containing crushed stone can be expected to maintain an SN above 35 during their 15-year design life only as long as the ADT does not exceed 350.

The skid resistance of many Class A bituminous surface treatments, on the other hand, can be expected to fall below an SN of 35 within one to four years, depending on the kind of aggregate in the surface and on the amount of traffic carried by the surface. A well-designed and well-constructed surface treatment using gravel aggregate probably would extend the skid life one or two years over those surfaces containing crushed stone.

DISCUSSION AND CONCLUSIONS

The preceding analyses have revealed that PCC pavements in Illinois generally have a higher value and a narrower range of skid resistance throughout their service life than most bituminous surfaces. Initial surface texture, rather than the kind and size of fine and coarse aggregate in the mixture, controls the skid resistance of PCC pavement surfaces. Highways constructed of PCC pavement should maintain a satisfactory skid number for most of their 20-year design life as long as studded tire wear is negligible, yet the same pavement placed in areas where 10 to 20 percent of the passenger cars have studded tires may need corrective treatment for skid resistance as early as five years after placement, depending on traffic volume.

Conversely, bituminous surfaces in Illinois usually have a lower skid resistance with greater variation than PCC pavements. Their skid resistance fluctuates with the size and the kind of coarse aggregate used in the mixture. Crushed gravel, air-cooled blast furnace slag and dolomites containing silica, have provided satisfactory skid-resistant surfaces, but limestone and some soft dolomites can lose their skid resistance rapidly even when used on lightly traveled highways.

Regardless of the type of aggregate used, excessive amounts of asphalt in bituminous concrete can fill voids in an otherwise textured surface and create a smooth, slippery surface when wet. Although a lean asphalt content can enhance skid resistance, too little asphalt in a mixture, on the other hand, can result in raveling and disintegration of that surface. Exercising close quality control at the plant while blending all materials is one way of assuring a uniform textured surface as the material is being placed. In turn, this can reduce variability in skid resistance of a bituminous concrete surface.

Skid tests indicate that a majority of two-lane highways in northern and central Illinois surfaced with bituminous concrete will maintain a satisfactory skid resistance throughout their 15-year design life, but a number of two-lane highways in southern Illinois will need corrective treatment for skid resistance considerably before the end of their structural design life.

Most County highways surfaced with bituminous concrete should maintain a satisfactory skid resistance throughout their 15-year design life as long as the ADT does not exceed 500 (80 percent fall in this category). Some County highways containing crushed stone coarse aggregate and carrying more than 350 vpd may need corrective treatment for skid resistance before the end of their normal service lives. Surfaces containing gravel and gravel blends, however, can expect to have an SN above 40 throughout most of their design life as long as the ADT is less than 1000.

County highways having Class bituminous surface treatments and carrying less than 1000 vpd usually will retain an SN above 35 for at least one year. Using pea gravel and other hard aggregates instead of crushed stone chips, however, can extend this same level of skid resistance at least one more year.

Having ascertained certain skid-resistance characteristics of paved surfaces in Illinois, the alternatives available for improving the skid resistance of pavement surfaces are appropriate for discussion now. The analyses performed in this study show a need for improving skid resistance, but the need is greater in bituminous concrete surfaces than in PCC pavements. The data indicate, however, that neither type of surface with the materials and procedures presently being used can be expected to retain a satisfactory skid resistance throughout their normal service lives on heavily traveled multi-lane expressways in metropolitan areas, and the need for corrective treatment for skid resistance before structural rehabilitation appears imminent.

As for new PCC surfaces, it appears that little can be done to enhance their skid resistance other than improving their initial surface texture. A coarser surface texture will improve skid resistance, but it also may increase road noise and degrade pavement riding quality. Texturing plastic concrete transversely with metal tines is becoming a popular way of increasing the skid resistance of new PCC surfaces without causing excessive road noise. Currently, one construction contract for 1975 paving will include six different methods of texturing the plastic concrete in addition to the existing burlap drag. The six different methods are longitudinal and transverse grooving with metal tines, longitudinal and transverse brooming, transverse grooving with a mechanical roller, and longitudinal dragging with artificial turf. The results obtained will be evaluated, considering also road noise and ride, and the best method(s) will be recommended for adoption.

As for bituminous surfaces, the alternatives for improving their skid resistance are less clearly defined than those for PCC surfaces because of a number of interacting factors that affect their skid resistance. Looking first at coarse aggregate, crushed gravel and most dolomite, which are quarried mostly in northern and central Illinois, provide higher skid numbers than the soft, fast-wearing and polishing limestone which is quarried in southern Illinois and neighboring States.

Regardless of aggregate type, aggregate gradations and asphalt content also affect skid resistance. Skid resistance is enhanced when the gradation of aggregate gives an optimum coarse-textured surface, which provides better drainage and reduces the chances of hydroplaning, and when the asphalt content is essentially equal to the design asphalt content.

Comparative tests on Route US 40 east of Troy indicate that blending air-cooled blast furnace slag (Mohs' hardness 6-7) with limestone (Mohs' hardness 3) improves the skid resistance of bituminous concrete in Illinois (11). Two places in Illinois where slag is available are the East St. Louis area (very limited supply) where the softer limestones prevail, and the Chicago area where many heavily traveled expressways are located. A new slag-dolomite surface placed in 1974 on Chicago area expressways had an initial SN in the low 60's. Moreover, the skid number-speed gradient was relatively flat. On Route US 40 near Troy, tests on another slag surface which has carried nearly 5 million axle applications and had an initial SN in the low 50's, suggest that a Class I bituminous concrete mixture containing air-cooled blast furnace slag will maintain a higher skid number for longer periods of time than the same mix with natural coarse aggregates. Hard skid-resistant aggregates produce higher initial skid numbers and resist wear and polishing better than soft limestone. Large supplies of high-quality skid-resistant aggregate, however, are not readily available in Illinois and are expensive.

Relative to primary and interstate highways, the most obvious alternative for improving the skid resistance of a Class I surface is to upgrade the skid-resistant characteristics of the coarse aggregate used in the mixture. The problem is most acute in southern Illinois and is related to the soft calcareous limestone coarse aggregate which is almost exclusively the local aggregate available for use in this area. Referring back to Table 3, a satisfactory skid life can be expected of Class I surfaces containing dolomite and crushed gravels on two-lane highways, on four-lane highways with ADT's up to 25,000, and on six-lane highways with ADT's up to 60,000. Limited experience indicates that these aggregates can be further upgraded skid-resistance-wise by blending in equal proportions with air-cooled blast furnace slag. The substituting of dolomite or crushed gravel for limestone in southern Illinois or the blending of the limestone with slag will reduce the use of presently available local aggregates and will increase the cost of Class I surface course construction by at least the additional cost of material shipping.

Further improvement could be obtained by improving the macrotexture of Class I surface by restricting coarse aggregate to the CA 13 gradation. The specifications presently require a 1/2-inch top-size coarse aggregate (CA 13 gradation) but permit the use of a 3/8-inch top-size aggregate (CA 16 gradation) so long as the surface course does not exceed 1 1/2 inches in thickness. Extended use is being made of the smaller size aggregate in some districts because of improved workability in constructing rundowns and in hand-placing the mixture. The 1/2-inch top-size aggregate improves the macrotexture of the surface and thus further enhances its skid-resistant characteristics.

A second alternative offering considerable potential for improving skid resistance is concerned with the use of thin skid-resistant surfaces as the wearing course. The required structural thickness is constructed of binder course utilizing presently specified aggregates, with the thin overlay functioning only as the wearing course and providing the needed skid resistance. This alternative offers the advantage of maximizing the use of locally available aggregates in the construction while minimizing the quantity of the more costly special skid-resistant aggregates required only for the thin wearing course. In urban areas and other locations where vehicular speeds do not exceed 45 mph, sand-asphalt mixes containing hard, angular, siliceous sands, with a rubber additive to improve overall performance, can be used (11). Sand-asphalt mixes, however, have fairly steep skid number-speed gradients and are not considered acceptable for rural high-speed highways.

The open-graded asphalt friction course developed in the western states offers good potential as a satisfactory wearing course for high-speed rural highways. Experience in Illinois with this type of construction presently is limited to three construction projects completed in 1974, all containing trap rock as the aggregate. Tests on the projects indicate that the surfaces have relatively flat skid number-speed gradients, but initial skid numbers were in the mid to upper 40's. It is anticipated that air-cooled blast furnace slag will produce higher skid numbers for this mix because of its vesicular structure which creates more microtexture, and plans for its use have been formulated. Experience to date in Illinois has shown that the procedures and controls governing the construction of the open-graded mix, while not believed to be more difficult than those governing dense-graded mixes, are sufficiently different that more experience is needed to assure proper construction, and also suggests that a determination of the applicability and limitations, if any, of this type of surface to the environmental and traffic conditions in Illinois should be made. The potential of the thin open-graded plant-mix asphalt friction course as a means of improving skid resistance certainly warrants continued experimentation to obtain the additional experience and knowledge needed.

Relative to secondary and local roads and streets, the skid resistance problem appears to be much less severe. The Class B surface normally used on these roads and streets can be expected to retain a satisfactory skid resistance for the structural design life as long as the ADT does not exceed 500, which covers the major mileage of these roads. For higher-volume roads and streets, the SN can be improved by eliminating the use of the soft calcareous limestones in the mix.

Surface treatments (seal coats), regardless of the aggregate used, appear to have relatively short skid-resistant lives. However, this is not considered a major problem since surface treatments are resealed periodically, and often annually. The use of gravel aggregate can be expected to extend the skid life of Class A surface treatments by one to two years over those containing soft limestone aggregate, but probably the most improvement in skid resistance will result from better application of perfected skills in construction to assure good retention of aggregate without bleeding.

RECOMMENDATIONS

Phases 2 and 3 of this research have given considerable insight into the skid-resistant characteristics of existing paved interstate, primary, and secondary and local systems of highways in Illinois. The study has dealt primarily with portland cement and bituminous concrete pavements and with surface treatments, as well as with the wearing and polishing of aggregates used in these pavements. It has outlined the areas of the State and the particular types of pavement in greatest need of improvement, and has provided sufficient information on which to base practical recommendations for changes that can be made now to improve and to prolong the skid resistance of new pavement surfaces. The study also has shed additional light on the overall complexity of the skid-resistance problem, and has helped to outline specific areas in need of additional information before recommendations for further improvement in skid resistance can be made.

Within the limits of the work covered in this study, the following recommendations are offered for consideration for immediate implementation:

(1) For all primary highways and for expressways carrying up to 25,000 vpd on four lanes or 60,000 vpd on six lanes which are to be surfaced with Class I bituminous concrete, upgrade the skid-resistant qualities of the coarse aggregate in the surface course mixture by prohibiting the continued use of soft calcareous limestone unless it is blended in equal proportion by volume with air-cooled blast furnace slag.

(2) Require that the coarse aggregate in Class I surface used on expressways carrying more than 25,000 vpd on four lanes or 60,000 vpd on six lanes or more lanes be air-cooled blast furnace slag or a 50-50 blend of this aggregate with crushed dolomite or crushed gravel.

(3) Improve the macrotexture of Class I surface course by using only the 1/2-inch top-size coarse aggregate (CA 13). Discontinue the permissive use of the 3/8-inch top size (CA 16).

(4) To help compensate for the added cost of upgrading the skid-resistant characteristics of the coarse aggregate as outlined above in (1) through (3), reduce the nominal thickness of Class I surface course from 1 1/2 inches to 1 1/4 inches.

(5) Eliminate the use of soft calcareous limestones in Class B surfaces on secondary and local roads and streets having an ADT in excess of 500 unless blended 50-50 with a slag aggregate.

In addition to the above, the following recommendations are offered to further improve the skid resistance of new pavement surfaces in Illinois.

(1) Adopt better methods for texturing PCC pavement. The experimental texturing study previously described should be completed as soon as

possible and the best method or methods immediately adopted and put into practice.

(2) Continue the experimental construction of open-graded plant-mix asphalt friction courses utilizing different types of aggregates to obtain the needed construction experience and to properly evaluate this type of surface for possible extended use in Illinois.

(3) Establish a program of experimental construction using the sprinkle treatment method with precoated aggregates. Although the few sprinkle treatments that have been tried in Illinois have not been spectacular, it is believed that this method holds promise as a way of enhancing skid resistance and offers the advantage of utilizing a very minimum of the more expensive high-quality skid-resistant aggregates.

(4) Continue searching for both natural and synthetic aggregates that will improve skid resistance of bituminous mixtures.

(5) Continue the search for laboratory tests or other methods that can be used to satisfactorily quantify and rate the skid-resistant characteristics of aggregates produced from various sources used in Illinois.

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